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Examining Socio-Demographics and Understanding Business Factors among Plastic Bottle Waste Collectors in Ogun State, Nigeria

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A B S T R A C T

This study examines the socio-demographic and economic experiences of plastic bottle waste (PBW) collectors and traders in Ijebu-Ode, Ogun State, through surveys. The study uses livelihood theory for context. The study shows that educational qualification, family size, religion, marital status, and age are more associated with PBW collection, while religion, gender, and age are more conducive to understanding the knowledge and attitudes of people who collect PBW for profit. Civilization, modern culture and consumption patterns, population, technology and industrial growth have influenced waste generation and collection for most people. Low recycling rates, inefficient waste disposal measures, and lack of knowledge about waste recycling hinder the collection of municipal waste and the development of the business. To improve the economic and social welfare of collectors and traders and reduce the impact of PBW on the environment, facilities and measures to formalize the business are advocated.

1. Introduction

Plastic bottle waste collectors mirror society's wastefulness. Garcia et al. (2018) found that South American people pass down trash picking as a culture. Trash collecting maintains a lifestyle that reinforces socioeconomic deprivation. Trash-related cultural norms keep this informal sector alive, making it hard to abandon regular professions and find alternative work. Also, cultural dynamics affect how communities see waste collectors. People in society and the community discriminate against rubbish collectors (Adetola et al., 2018; Solaja et al., 2023). Internal marginalization might make plastic bottle collectors' jobs harder. Khan et al. (2021) suggest that community-based treatments are essential for waste collectors' social integration due to cultural attitudes. Plastic bottle garbage collectors affect society beyond the economy (Solaja et al, 2023).

Environmental sustainability requires recycling and trash management. Waste collectors rarely obtain help from structured rubbish management systems despite their importance. Uncredited work increases socioeconomic fragility. Social and environmental actions are needed to break this cycle.

Lack of legal recognition and social protection makes waste collectors vulnerable, raising social justice problems (Roy, 2010; Solaja, 2019). Few trash streams make plastic bottle waste collection harder (Lwasa et al., 2019). Age, gender, education, and family size affect waste collectors' hazards and issues (Ojo et al., 2017). Waste collecting can be profitable, but its informality and uncontrollability stigmatize waste collectors (Medina,

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2010; Adetola et al., 2018; Solaja, 2019). Understanding waste collectors' demographics is vital. Understanding their needs and challenges is crucial to finding solutions, according to Gupta and Bleakley (2019). Though waste collectors are increasingly valued (Solaja et al., 2023), little is known about their socio-demographic features in Nigeria. This study examines Ijebu-Ode, Ogun State, plastic bottle garbage collectors. The literature discusses waste-picking and socio-demographic consequences. Age and gender affect waste collectors' susceptibility, say Ojo et al. (2017). Younger people and women may encounter different obstacles. According to a UK study of 90,000 people from 40,000 families, some demographic groups were more environmentally friendly. Older women, childless couples, and couples with children were included (Longhi, 2013). Retired people did less, while an Indian study found that males, middle-aged people, and married people scored better on PEB. Chen et al., 2011 observed that young, female, and well-educated people cared less about the environment. Many Australian workers, 30 to 44-year-olds were the largest age group, followed by 45-64 and those over 65. The 18 to 29-year-olds were calmer.

Men 18-29 were less eco-conscious than women 45-64. The College of Natural Resources has more eco-friendly students than the College of Agriculture. A study found that teaching youngsters, especially environmentalists, eco-friendly behavior may influence their policymaking. Nigerian plastic bottle garbage collectors differ by religion, family size, education, marital status, and region.

This socio-demographic perspective illuminates the complex relationships between education, occupation, and waste collectors' socioeconomic status (Wilson and Velis, 2019). Literature extensively discusses socio-demographic profiles. While some say it fosters stereotypes, others say it is adjustable. Ramos et al. (2021) propose that responsible profiling can challenge prejudices and foster empathy by showing waste collectors' diverse and complex lifestyles. However, stigmatization and privacy concerns warrant ethical research (Rathore et al., 2018). Since waste management solutions are not universal, especially in Nigeria, a diverse and ever-changing nation, socio-demographic profiling is needed. Socio-demographic research on plastic bottle waste collectors can reveal complicated factors affecting their roles, challenges, and contributions. According to Gupta and Bleakley (2019), waste collectors' socio-demographic characteristics must be considered when designing treatments. Demographics also explain waste collectors' socioeconomic vulnerabilities. This understanding promotes inclusive and equitable waste management (Wang et al., 2020).

This takes a look at seeking to address this hollow by way of searching into the socio-demographic and economic characteristics of PBW collectors and buyers in Nigeria, in particular in Ijebu-Ode, Ogun State, Nigeria. To achieve this goal, this paper is thematically structured into various sections namely research questions, hypotheses, literature review, theoretical framework, methodology, results and discussions, conclusion and recommendations.

1.1. Research Questions and Hypotheses

The following research questions and hypotheses guided the study;

1. To what degree do collectors of plastic bottle waste (PBW) experience the social and economic dynamics inherent in the PBW business?
2. What is the collective impact of demographic variables among respondents on their understanding of plastic bottle waste (PBW) collection as a business?
3. To what extent are plastic bottle waste (PBW) collectors immersed in and influenced by the social, economic, and cultural dynamics of the PBW business?

1.2. Literature Review

The literature review examines existing research on plastic bottle waste (PBW) management, focusing on legislative measures, recycling initiatives, and the socioeconomic impacts of PBW generation and collection. Previous studies have highlighted the need for sustainable waste management strategies and the importance of understanding the demographics and economic experiences of individuals involved in PBW collection and trading. However, information is presented under the following subheadings.

2. Nigerian Plastic Waste Management

Due to the growing challenges of plastic manufacturing and disposal, Nigerian plastic waste management is complex and urgent (Adebisi and Ogunseye, 2018; Solaja et al., 2023). Plastics are produced in 368 million metric tons worldwide, causing environmental damage (Geyer et al., 2017). Nigeria's rapid population expansion and urbanization burden waste management facilities (Ezedike et al., 2020; World Bank, 2021). The growing usage of throwaway plastics exacerbates environmental degradation, requiring immediate and effective trash management (Adebisi and Ogunseye, 2018; Solaja, et al., 2023). Nigeria is experiencing a critical socio-economic issue with plastic waste. This issue is especially visible among marginalized waste collectors, whose livelihoods depend on plastic waste collection and sale (Solaja et al., 2017; Adebisi and Ogunseye, 2018; Solaja et al., 2023). The collection of garbage has become a vital way for economically disadvantaged people to make money (Solaja et al., 2023), illustrating the interwoven socioeconomic concerns that must be addressed to manage plastic waste in Nigeria.

Sustainable waste management in Nigeria is complicated by its socioeconomic environment. Understanding the socio-demographic features of plastic garbage collectors is essential to improving waste management (Gupta and Bleakley, 2019). Nigeria needs a waste management system that addresses waste collectors' unique requirements, challenges, and contributions. Nigeria needs plastic waste management, according to Adebisi and Ogunseye (2018). They highlight the growing amount of plastic waste and the need for specialized and comprehensive environmental solutions. Social, economic, and cultural factors that affect plastic garbage collectors worsen the situation. An in-depth analysis is needed to comprehend the intricacies of plastic garbage collection and exchange and identify barriers, inefficiencies, and improvement opportunities.

Plastic waste management must overcome logistical and socioeconomic challenges to be effective. Understanding these problems is essential to creating long-term solutions that address plastic waste management inefficiency. Given the escalating challenges of plastic production, population growth, and urbanization, this complex issue needs an immediate and customized response. Comprehensive measures tailored to Nigeria's socio-economic conditions are needed to address these issues. The socio-demographic characteristics of waste collectors and the challenges of collecting and selling plastic waste highlight the need for specific interventions and research. By solving these complicated issues, Nigeria may be able to handle plastic trash more sustainably and efficiently. This would significantly aid global plastic waste reduction efforts.

3. Waste collectors' Recycling Role

Waste collectors are vital to the recycling ecosystem and worldwide waste management. Trash collectors, sometimes known as scavengers or recyclers, are informal workers who collect, sort, and sell recyclable products from trash streams, according to Medina (2011). Their contributions go beyond waste collection and include key recycling value chain elements. Trash collectors are especially prevalent in developing countries with weak trash management systems (Medina, 2010; Solaja, et al., 2023).

Many urban garbage collectors intercept recyclable goods from families, businesses, and formal waste management systems before they end up in landfills. Their recycling efforts prevent valuable resources from being discarded. Scheinberg et al. (2010) highlighted that waste collectors help recover resources, decreasing waste's environmental impact and maximizing material use. Waste collectors' socioeconomic impact is huge.

Many marginalized people make a living via rubbish picking. This is especially true in underdeveloped nations with few formal jobs. Waste picking is a crucial source of income for individuals and their families (Beluský et al., 2020). Including waste collectors in the recycling value chain empowers people economically and reduces poverty in their communities. The informality of waste picking makes it difficult and stigmatizing. Insufficient legal recognition and social protection increase their vulnerability (Medina, 2010; Roy, 2010). Recognizing waste collectors' recycling activities and offering legal and social assistance are essential to improving their working conditions.

Trash collectors' recycling success depends on their access to trash streams, local waste management systems, and market demand for recyclables. Access to waste streams may limit waste collectors' contributions, emphasizing the need for inclusive waste management (Lwasa et al., 2019). Collaborations between refuse collectors and formal waste management systems can boost recycling efficiency and recover recyclable resources. Waste collectors change waste management habits as well as collect. Their deep understanding of local waste sources makes them important community-based trash management partners. Beluský et al. (2020) suggest integrating waste collectors into formal waste management institutions for more sustainable and inclusive solutions. This integration allows waste collectors to contribute their skills while improving working conditions and social recognition. Waste collectors help recycle, recover resources, alleviate poverty, and manage waste sustainably. Building inclusive and successful waste management systems requires acknowledging and resolving their contributions and limitations. Trash collectors may continue to promote sustainable trash management and recycling worldwide through legal recognition, social support, and collaboration.

4. Potential Drawbacks of Formalizing Waste Picking Business

Formalizing waste-picking firms to improve labor conditions and socioeconomic status may have negative repercussions that must be examined and mitigated. Since waste collectors have always worked informally, formalization may reduce their flexibility and freedom (Solaja et al., 2023). Waste picking is flexible enough to adapt to shifting waste streams and market conditions. Formalization may impose inflexible structures that hinder waste collectors' ability to adapt, affecting their livelihood. To tackle this difficulty, flexible formalization models that recognize trash picking's unique characteristics are needed. Beluský et al. (2020) suggest a gradual, participatory approach to formalization, incorporating waste collectors' perspectives and allowing for adaptability.

Formalization may also increase waste collectors' administrative duties (Medina, 2010). Compliance with regulations and paperwork can distract people from productive work, reducing their efficiency and income.

This issue requires effective and simplified administrative procedures to reduce bureaucratic impediments. Scheinberg et al. (2010) found that incorporating waste collectors in formalization policy creation can help identify effective administrative barriers, assuring their feasibility for those involved.

Formalization may also impose admission requirements that prevent some waste collectors from participating (Solaja, 2019). Exclusion may exacerbate social inequities and limit waste management system inclusivity. Diversity-focused policies are needed to address this issue. According to Lwasa et al. (2019), participatory techniques and incorporating many garbage collector groups in decision-making can prevent some waste collectors from being excluded during formalization.

Waste collectors may face economic challenges when transitioning from informal to formal systems, such as the cost of equipment or compliance with legislation (Beluský et al., 2020). Many waste collectors may struggle to move due to financial pressure. Microfinance initiatives or subsidies might help rubbish collectors meet the initial costs of formalizing their job. Support systems are essential for fair and equal formalization benefits (Scheinberg et al., 2010). Formalizing rubbish collector communities may unintentionally undermine social networks and relationships (Medina, 2010; Roy, 2010; Solaja et al., 2023). The change from informal to formal institutions may affect waste collectors' social cohesion and reciprocal support. A careful, community-focused formalization plan is needed to address this issue. Involving waste collectors in planning and execution, as suggested by Beluský et al. (2020), preserves social structure and aligns formalization with common aims.

Formalizing waste-picking businesses can improve waste collectors' working conditions and socioeconomic status.

5. Environmental Impacts of Plastic Bottle Waste Collection and Recycling

The collection and recycling of plastic bottle waste by garbage collectors, although it provides economic opportunities, might have environmental consequences that, in certain instances, may surpass the economic advantages. Studies indicate that the process of gathering and reusing plastic bottles can have both positive and negative consequences, requiring careful consideration of environmental factors. An environmental concern arises from the energy-intensive procedures utilized in the recycling of plastic bottles. As to the findings of Jambeck et al. (2015), the recycling of plastic bottles, specifically the processes of melting and reprocessing, requires a significant amount of energy. The energy requirement, frequently obtained from non-renewable sources, adds to carbon emissions, therefore offsetting certain environmental advantages linked to recycling.

Furthermore, the act of recycling plastic bottles may not completely alleviate the issue of plastic pollution. The study conducted by Geyer et al. (2017) emphasizes that despite the presence of effective recycling systems, a considerable amount of plastic trash, such as bottles, still finds its way into the environment due to insufficient collection, sorting, and recycling infrastructures. This raises apprehensions over the overall effectiveness of plastic bottle recycling in mitigating environmental consequences. The widespread usage of disposable plastic bottles worsens the environmental consequences due to the resource-intensive manufacturing process and its contribution to the depletion of fossil fuels. The creation of plastic bottles entails the extraction and refining of petroleum, which is a finite resource (Andrady, 2017). Hence, the extensive use of disposable plastic bottles exacerbates the environmental impact linked to the collecting and recycling of plastic bottle trash.

In addition, the transportation of gathered plastic bottles to recycling facilities might result in carbon emissions, especially if waste collectors lack access to eco-friendly means of transportation (Pivnenko et al., 2016). This aspect highlights the significance of taking into account the complete life cycle of plastic bottle waste management to appropriately evaluate its environmental impact. The recycling process also poses possible environmental concerns due to the emission of microplastics. During the recycling of plastic bottles, the mechanical processes involved might create and release microplastic particles into the environment (Rillig, 2012).

Microplastics, when they accumulate, present ecological hazards, especially in aquatic settings, where they can have detrimental impacts on marine organisms. Although waste collectors play a role in recycling, it is important to consider the overall environmental consequences about the economic advantages. The economic benefits for waste collectors may be undermined by the adverse external effects linked to the collection and recycling of plastic bottles. The study conducted by Pivnenko et al. (2016) indicates that the economic advantages of waste collectors can be negated by the negative environmental consequences if recycling procedures are not carried out sustainably.

6. Ethical Issues Surrounding Waste Collectors in the Management of Hazardous Waste

The involvement of waste collectors in managing hazardous waste materials gives rise to notable ethical considerations that necessitate thoughtful deliberation and focus. Garbage collectors, frequently found in the informal sector, have a vital function in garbage management, encompassing the gathering and categorization of materials. Nevertheless, when it comes to managing hazardous waste, which presents potential dangers to both human well-being and the ecosystem, ethical issues take on utmost importance. An important ethical issue is the well-being and safety of waste collectors who are exposed to dangerous substances while performing their job. Hazardous waste inherently consists of compounds that possess toxicity, carcinogenicity, or other detrimental effects on human health (Ezeah et al., 2013). Insufficient protective precautions when handling such materials expose waste collectors to both immediate and long-term health risks, such as respiratory problems, skin disorders, and chronic diseases. Research has emphasized the perilous circumstances encountered by waste collectors who handle dangerous waste. In their study done in South Africa, Ezeah et al. (2013) discovered that waste collectors were involved in the gathering and categorization of electronic waste, which consists of dangerous substances such as heavy metals and flame retardants. The study found that a significant proportion of waste collectors did not possess adequate protective equipment, resulting in their direct exposure to perilous compounds. To tackle this ethical issue, a comprehensive approach must be taken that places the health and safety of waste collectors as a priority. It is crucial to implement strict safety measures, supply personal protective equipment (PPE), and conduct training programs on managing hazardous waste (ILO, 2018). It is imperative to incorporate waste collectors into established waste management systems while implementing appropriate rules and safety requirements, to guarantee ethical behavior in the handling of hazardous material.

Another ethical concern pertains to the socio-economic susceptibility of waste collectors. rubbish collectors, who are frequently marginalised and have economic disadvantages, may feel obligated to handle dangerous rubbish since they have limited other options for employment (Asibey, et al., 2019). The economic imperative gives rise to ethical concerns regarding the utilisation of susceptible communities to handle and dispose of dangerous waste materials. To tackle this issue, it is necessary to implement more comprehensive socio-economic interventions that offer alternate means of making a living for individuals who collect rubbish.

The involvement of both governmental and non-governmental organisations is crucial in developing initiatives that provide training, education, and other job opportunities. This will help decrease the reliance of waste collectors on handling dangerous waste items (Lohri et al., 2015).

Moreover, the absence of legal acknowledgement and societal safeguards for garbage collectors exacerbates the ethical issues associated with their participation in the management of hazardous waste. Due to the informal nature of their labor, waste collectors typically face a lack of healthcare, insurance, and other social benefits, making them susceptible to the negative consequences of their occupation (Black et al., 2019; Solaja 2019; Karki, et al., 2022;). Recognizing waste collectors as vital contributions to the waste management system and providing them with legal protection and social support is imperative from an ethical standpoint. Research conducted by Lohri et al. (2015) highlights the significance of incorporating waste collectors into established waste management systems, granting them legal acknowledgement and social safeguards.

Formalization serves the dual purpose of ensuring ethical treatment and enabling the formation of explicit standards and regulations for the management of hazardous waste. This safeguards the well-being of waste collectors and protects the environment.

Moreover, the ethical issues related to waste collectors and hazardous waste also encompass the possible environmental consequences of inadequate handling and disposal. Insufficient knowledge or resources among garbage collectors to handle hazardous materials responsibly may result in the contamination of soil, water, and air, hence causing detrimental effects on ecosystems and populations (Ezeah et al., 2013). To tackle this ethical challenge, it is imperative to develop extensive waste management systems that integrate waste collectors while protecting environmental purity. The primary focus of government legislation and industry actions should be to give priority to the appropriate handling and elimination of hazardous waste, to prevent garbage collectors from unintentionally contributing to the deterioration of the environment (ILO, 2018).

7. Previous Research on Waste Collectors and Recyclers

Previous research on socio-demographic profiling within the context of waste collectors and recyclers provides valuable insights into the multifaceted dimensions of their work. Numerous studies have explored the socio-economic characteristics of waste collectors, shedding light on their demographics, income sources, and living conditions. For instance, a study by Scheinberg et al. (2010) conducted in various cities worldwide delved into the socio-economic profiles of waste collectors, emphasizing their diverse backgrounds and the critical role they play in informal waste management systems. Medina (2010) contributed significantly to the understanding of waste collectors by examining their livelihood strategies, highlighting the economic significance of waste picking in developing countries. The research emphasized the informal nature of waste picking as a source of income for marginalized individuals who often face limited formal employment opportunities. This socio-economic perspective is crucial for recognizing the broader implications of waste collectors' work on poverty alleviation and community well-being. In addition to socio-economic aspects, studies have explored the demographic composition of waste collectors, considering factors such as age, gender, and education levels. The research by Beluský et al. (2020) focused on waste collectors in various global contexts, revealing variations in demographics across different regions. Understanding these demographic factors is essential for tailoring interventions that address the specific needs and challenges faced by different groups of waste collectors.

The socio-demographic profile of waste collectors also intersects with issues of social justice and equity. Many waste collectors, particularly in developing countries, belong to marginalized or vulnerable groups, facing discrimination and stigmatization due to the informal nature of their work. Recognizing and addressing these social justice dimensions are crucial for developing inclusive policies and interventions (Solaja, 2019; Fuss, et al., 2021; Solaja et al., 2023). Moreover, the impact of socio-demographic factors on waste collectors' access to resources and opportunities has been a subject of scholarly inquiry. Lwasa et al. (2019) conducted research that examined the relationship between demographic variables and waste collectors' access to waste streams. The findings underscored the importance of inclusive waste management practices that consider the socio-demographic dimensions of waste collectors to optimize the efficiency of resource recovery.

Research has also highlighted the intersectionality of socio-demographic factors with other aspects of waste collectors' lives, such as health and well-being. Understanding the connections between demographic variables and health outcomes is critical for developing holistic interventions that address the broader welfare of waste collectors. Studies by Scheinberg et al. (2010) and Medina (2011) have explored these connections, emphasizing the need for comprehensive approaches that consider the socio-demographic context of waste collectors.

Furthermore, the geographical context plays a significant role in shaping the socio-demographic profiles of waste collectors. Research conducted by Beluský et al. (2020) across diverse regions provided valuable insights into the contextual variations that influence the demographics and experiences of waste collectors. This emphasizes the importance of context-specific interventions that account for the unique socio-demographic characteristics of waste collectors in different locations.

In conclusion, previous research on socio-demographic profiling of waste collectors has contributed significantly to our understanding of the diverse dimensions of their work. The studies reviewed have delved into socio-economic factors, demographics, social justice issues, access to resources, health outcomes, and geographical variations. Recognizing the socio-demographic context of waste collectors is essential for developing targeted and effective interventions that address the unique challenges and contributions of this critical workforce in the realm of waste management and recycling.

8. Theoretical Framework

The socio-demographic profiling of plastic bottle waste collectors in Nigeria can be comprehensively examined through the lens of livelihood theory, a framework that emphasizes the role of assets, capabilities, and vulnerabilities in shaping the livelihoods of vulnerable populations (Chambers and Conway, 1992). Building on the extensive literature in this field, previous studies have successfully applied livelihood theory to understand the socio-economic dynamics of informal economies, particularly within the context of waste picking (Scoones, 2009; Van der Ploeg, 2015).

Applying the livelihood theory as our guiding framework, we scrutinize various assets that contribute to the livelihoods of plastic bottle waste collectors. Human capital factors, such as age, education, and skill levels, play a pivotal role in shaping their capabilities (Ellis, 1998). Studies have shown that education positively affects the livelihood outcomes of vulnerable populations in informal sectors, underscoring the importance of human capital in shaping livelihoods (Beegle et al., 2006). Social capital, manifested in the form of networks and relationships within the waste-picking community, is another crucial asset (Portes, 1998; Solaja, et al, 2017).

Research by Uphoff (1986) illustrates the significance of social capital in providing support and resources for individuals engaged in informal economies. The interaction between waste collectors and their environment constitutes a dimension of natural capital, reflecting the dependence of vulnerable populations on environmental resources (Berkes et al., 2003). Financial capital, encompassing income levels, savings, and access to financial resources, is a critical component of the livelihood framework (Deaton, 1997). Studies have highlighted the link between financial capital and improved livelihood outcomes in informal economies (Harold and Garcia Poverty, 1993).

Examining vulnerabilities and coping strategies within the socio-demographic profile of plastic bottle waste collectors allows for a nuanced understanding of their livelihood challenges. Socio-demographic factors contribute significantly to vulnerabilities, and a review of studies on waste collectors reveals how these individuals adopt coping strategies in the face of challenges (Scheinberg et al., 2010). The livelihood strategies employed by waste collectors, including the diversification of income sources within waste picking, align with existing literature illustrating how vulnerable populations navigate the complexities of informal economies (Carr, 2008). Gender dynamics further shape the socio-demographic profile of waste collectors, with studies highlighting gender-specific challenges and opportunities within this context (Roy, 2010). Livelihood theory provides a lens through which we can understand the gendered aspects of plastic bottle waste picking and the implications for the socio-demographic composition of this workforce. Drawing policy implications through a livelihood lens is crucial for addressing the challenges faced by plastic bottle waste collectors. Understanding how policies can enhance livelihood assets and reduce vulnerabilities is essential (Ellis, 2000). Research by Narayan et al. (2000) provides insights into how policy interventions can positively affect the livelihoods of vulnerable populations. Social networks also emerge as a critical factor in shaping the livelihoods of waste collectors, aligning with literature that underscores the importance of social networks in the functioning of informal economies (Woolcock and Narayan, 2000). In conclusion, the application of livelihood theory enriches our comprehension of the socio-demographic profiling of plastic bottle waste collectors in Nigeria. By examining assets, vulnerabilities, and coping strategies through this lens, we gain a holistic understanding of the dynamics at play within this informal sector. This analysis, grounded in the principles of livelihood theory, not only contributes to academic discourse but also provides actionable insights for policy formulation and interventions tailored to the unique challenges faced by plastic bottle waste collectors in Nigeria.

9. Measures and Methods

This study, conducted in the Ijebu region of Ogun State, Nigeria, utilizes a descriptive and exploratory survey design. Using a semi-structured questionnaire as the main data collection method, the study centers on semi-urban areas (Ago-Iwoye, Ijebu-Igbo and Ijebu-Ode) in the Ijebu region. These areas were selected using a convenience sampling technique, and participant inclusion was determined using a quota sampling method. This study seeks to investigate the socio-demographic characteristics of individuals who engage in the collection of plastic bottle waste in specific locations in the Ijebu region of Ogun State. Based on the vibrant cultural backdrop of Ijebu, which is known for its traditions, festivals, and a strong sense of community, this study has the potential to provide valuable insights for shaping policies and governance structures. In addition, a quota sampling procedure was used to select 94 participants who were ecopreneurs or individuals actively engaged in the plastic waste industry and possessed significant expertise in the subject matter. Nonetheless, 86 participants (91.4 %) fulfilled the inclusion criteria and actively took part in the survey. Participants were required to be Nigerian citizens with at least five years of experience in the plastic waste industry in the selected locations. Quantitative data were collected through a questionnaire, and the analysis utilized descriptive methods such as frequency counts and percentage distribution tables. In addition, inferential analysis was performed using a one-sample t-test, independent t-test, and chi-square. The methods used in this study allowed for a thorough exploration of the socio-demographic characteristics and waste management perspectives of the participants.

In addition, this study was conducted with a strong focus on ethical principles, ensuring that participation was voluntary and that the participants' identities and information remained confidential. All respondents were given prior consent, ensuring clear communication about their right to withdraw from the study and the choice to not answer any intrusive questions. Parental or guardian permission was obtained for participants under the age of 18. During the questionnaire administration, parents or guardians were permitted to accompany underage participants to ensure their comfort and well-being. Participants were given the assurance that the information they provided would be used solely for research purposes, with a commitment to maintaining their anonymity and confidentiality. Even though the University's ethical review committee was not in place during the study, the investigation was conducted with utmost dedication to ethical principles. The tested variables are presented in Table 1.

Table 1
Tested Key Variables (Researcher’s Formulation, 2021)

Generation and Collection
Generation is increasing daily a person generates an average of 16 kg PBW per day.
Mostly generated from households, marketplaces, restaurants, workplaces, religious and event centres.
Polyethylene terephthalate (PET), polyethene (PE), polypropylenes (PP), polystyrenes (PS), and polyvinyl chloride (PVC) are found among the PBW generated.
More noticeable than other solid waste.
Polyurethanes and epoxy resin were found among the PBW generated.
PBW waste is easier to collect after single-use or throwaway.
PBW is more convenient for collection and sorting than other solid waste.

Table 1 Continued
Tested Key Variables (Researcher's Formulation, 2021)

Generation and Collection
PBW can be sorted and stored easily for recycling conveniently.
PBW can be picked from open dumps and domestic waste bins.
PBW can be conveyed from the point of disposal to the collection centre wheelbarrow, sacks, cartoons etc.
PBW is frequently collected after use because of its multiple utilities.
PBW is collected by scavengers, children, women and youths.
PBW is lightweight and durable for a recycling activity or process.
PBW is also collected through authorized waste bins or bags provided by the government.
Social Dynamics
PBW trading is being carried out in both rural and urban areas; PBW trading is not gender-biased.
PBW trading gives room for apprenticeship and family business initiatives.
PBW trading also promotes cluster networks and partnerships among ecopreneurs.
PBW trading is not age-based.
PBW trading does not require formal education and registration.
Economic Dynamics
Trading is lucrative and promising.
Trading promotes self-employment and income for generations.
Trading generates monthly income.
Trading is not capital-intensive compared to other informal businesses.
Trading requires general trading skills (buying, storing and selling),
Recycling serves as a resource for recycling and sustainable industrial activities.
Recycling helps in reducing the cost of purchasing fresh resources from manufacturers.
Recycling contributes to the level of informal economic activities.
Recycling serves as an alternative source of the international waste business.
Recycling saves the cost of plastics production and management.
Recycling creates more eco-friendly business initiatives and opportunities.
Recycling enables the chance of turning waste into consumable and reusable materials.
Recycling helps to reduce and save the use of finite materials such as crude oil for plastics production.
Recycling enhances the re-invention of old things in new ways.
Recycling encourages the production and consumption of affordable as well as recyclable products.
Recycling helps to promote the flow of wealth or financial resources among indigenous individuals and industries.

Table 1 Continued
Tested Key Variables (Researcher's Formulation, 2021)

Economic Dynamics
Recycling allows for creativity and re-creativity among individuals and industries.
Recycling helps to create additional wealth from unwanted materials.
Recycling boosts the rate of application of plastics in the contemporary world.
Recycling encourages new investors especially when sorting and collection are carried out properly; has a high market value if processing plants are available.
Cultural Dynamic
PBW trading is compatible with the culture of people.
Plastic Bottle Waste Collection as a Business
Trading is carried out through the buying and selling of used plastics.
Trading is being carried out in both rural and urban areas.
Trading gives room for apprenticeship and family business initiatives.
Trading does not require formal education and registration.

10. Results

In this section, the results of the data gathered using the research methods explained earlier are presented. The aggregate and disaggregate approaches were used. By aggregate approach, the demographics, attitudinal and knowledge variables are presented cumulatively. Data in Table 2 indicate the extent to which participants experienced dynamics earlier presented in Table 1. According to the data, they had experience of social dynamics ($t = 40.585$, $df = 61$, $P < .000$) more than economic dynamics ($t = 102.953$, $df = 45$, $P < .000$).

However, on examination concerning mean value, the economic dynamics are more dominant (Mean difference = 20.21739) than social dynamics. These results are explored further in Tables 3, 4 and 5 with the consideration of individual demographic variables. Data in Table 3 explicates the connection between the varied demographics of the participants and the social dynamics of collecting and trading PBW. From the data, it emerged that participants between 21 and 26 years align with the dynamics ($M = 6.5000$, $SD = .57735$) mostly followed by those who indicated 39 years above as their age ($M = 6.4000$, $SD = .50262$). Within the marital status, participants who have not married ($M = 6.7500$, $SD = .84699$) and those who have divorced ($M = 6.5000$, $SD = .57735$) resonate with the dynamics more than the other categories examined. Male participants are more inclined with the dynamic ($M = 6.5455$, $SD = .80043$) than female participants.

Excluding participants of single marital status, one can conclude that the dominance of 5-8 ($M = 6.6154$, $SD = .75243$) and 1-4 ($M = 6.4286$, $SD = .51355$) persons family size indicates that divorcees, separated and married participants believe in tested social dynamic variables.

This is better understood within the context of improving their means of livelihood. In the area of religion, participants with African Traditional beliefs ($M = 8.0000$, $SD = .00000$) and Christian doctrines ($M = 6.5333$, $SD = .62881$) are more attuned to the dynamics than those who believe in Islamic beliefs.

Table 2
Extent PBW collectors experience the social, economic and cultural dynamics of the PBW business (Researcher's Analysis, 2023)

	Test Value = 3					
	T	Df	Sig. (2-tailed)	Mean Difference	95 % Confidence Interval of the Difference	
					Lower	Upper
Social Dynamics	40.585	61	.000	3.45161	3.2816	3.6217
Economic Dynamics	102.953	45	.000	20.21739	19.8219	20.6129

Table 3
Social Dynamics by Demographics (Researcher's Analysis, 2023)

Age	N	Mean	Standard Deviation
15-20 Years	6	6.0000	.00000
21-26 Years	**4**	**6.5000**	**.57735**
33-38 Years	2	6.0000	.00000
39 Years Above	**20**	**6.4000**	**.50262**
Marital Status			
Single	**24**	**6.7500**	**.84699**
Married	22	6.2727	.45584
Divorced	**4**	**6.5000**	**.57735**
Separated	10	6.2000	.42164
Gender			
Male	**22**	**6.5455**	**.80043**
Female	40	6.4000	.59052
Family Size			
1-4 Persons	**14**	**6.4286**	**.51355**
5-8 Persons	**26**	**6.6154**	**.75243**
More than 8 Persons	20	6.3000	.65695
Religion			
Christianity	**30**	**6.5333**	**.62881**
Islam	28	6.2143	.56811
African Traditional	**2**	**8.0000**	**.00000**
Educational Level			
No Formal Education	10	6.2000	.42164
Primary School Education	**24**	**6.5000**	**.78019**
Secondary Education	**22**	**6.4545**	**.67098**
Tertiary	**4**	**7.0000**	**.00000**

Analysis of the educational level along with the dynamics shows that tertiary education (M = 7.0000, SD = .00000), primary school education (M = 6.5000, SD = .78019) and secondary education (M = 6.4545, SD = .67098) qualification holders experienced the dynamics more than others. These results have indicated that participants cannot have the same views despite doing the same trading activity. This is expected to reflect in their knowledge and attitudes of economic dynamics. Similar to what was presented in Table 3, data in Table 4 establish a link between the individual demographics of the participants with the economic dynamics. Analysis indicates a clear disparity in the age categories that resonate with social and economic dynamics. According to the data in Table 3, participants who indicated 33 to 38 years (M = 26.0000, SD = .00000) as their age are more aligned with the economic dynamic than those who reported 15 to 20 years (M = 23.0000, SD = 1.54919).

These two age categories are better than other categories. The emergence of the participants with 33 to 38 years is quite revealing when one looks at the number of people in the family size earlier reported under the social dynamics, which indicates a dominant connection of those with divorced marital status with the dynamics [social]. On the other hand, the result is surprising in the context that the participants with 21 to 26 years of age, who earlier aligned with social dynamics, are not found in the economic dynamics. This suggests that older participants considered the economic benefits of engaging in PBW collection and trading more than young participants did.

This position is further justified by the highest standard deviation of the economic-related attitudes and knowledge of married participants (M = 23.4286, SD = 1.45255) than the participants with single marital status (M = 23.6364, SD = 1.25529) and others. From the data, it could be inferred that male participants (M = 23.3636, SD = 1.39882) were more related to economic dynamics.

This is not different from what was discovered for social dynamics. The dominance of participants with more than an 8-person family size (M = 23.8889, SD = 1.40958), 1-4 persons; (M = 23.2000, SD = 1.22927) indicates that the participants believed in capturing economic benefits from collecting and trading PBW.

This aligns with the earlier position that participants are engaging in the two activities of PBW because of the need to increase their means of livelihood. Like social dynamics, participants who reported African Traditional (M = 24.0000, SD = .00000) and Christianity (M = 23.2727, SD = 1.31590) as their religions also associated with economic dynamics more than the believers of Islamic doctrines did. Participants, according to the data in Table 4, with primary school education (M = 23.5556, SD = 1.38148) and tertiary education (M = 23.5000, SD = .57735) connected with economic dynamics than others, who have secondary education qualification and those without formal education. With this result, it could be concluded that primary school leavers and those with tertiary education qualifications are engaging in the collection and trading of PBW as an alternative to getting a white-collar job. Table 5 establishes cultural views that the participants' demographics aligned with.

Table 4
Economic Dynamics by Demographics (Researcher's Analysis, 2023)

Age	N	Mean	Standard Deviation
15-20 Years	**6**	**23.0000**	**1.54919**
21-26 Years	4	22.5000	.57735
33-38 Years	**2**	**26.0000**	**.00000**
39 Years Above	12	22.6667	.98473
Marital Status			
Single	**22**	**23.6364**	**1.25529**
Married	**14**	**23.4286**	**1.45255**
Divorced	2	22.0000	.00000[a]
Separated	6	22.0000	.00000[a]
Gender			
Male	**22**	**23.3636**	**1.39882**
Female	24	23.0833	1.28255
Family Size			
1-4 Persons	**10**	**23.2000**	**1.22927**
5-8 Persons	16	22.6250	1.02470
More than 8 Persons	**18**	**23.8889**	**1.40958**
Religion			
Christianity	**22**	**23.2727**	**1.31590**
Islam	20	22.9000	1.33377
African Traditional	**2**	**24.0000**	**.00000**
Educational Level			
No Formal Education	8	23.0000	1.30931
Primary School Education	**18**	**23.5556**	**1.38148**
Secondary Education	14	23.0000	1.46760
Tertiary	**4**	**23.5000**	**.57735**

Table 5
Cultural Dynamics by Demographics (Researcher's Analysis, 2023)

Age	**N**	**Mean**	**Standard Deviation**
15-20 Years	6	1.0000	.00000
21-26 Years	**4**	**1.5000**	**.57735**
33-38 Years	2	1.0000	.00000[a]
39 Years Above	20	1.0000	.00000[a]
Marital Status			
Single	**24**	**1.2500**	**.44233**
Married	22	1.0909	.29424
Divorced	4	1.0000	.00000[a]
Separated	10	1.0000	.00000[a]
Gender			
Male	22	1.0909	.29424
Female	**40**	**1.1500**	**.36162**
Family Size			
1-4 Persons	**14**	**1.1429**	**.36314**
5-8 Persons	**26**	**1.2308**	**.42967**
More than 8 Persons	20	1.0000	.00000
Religion			
Christianity	**30**	**1.1333**	**.34575**
Islam	**28**	**1.0714**	**.26227**
African Traditional	2	1.0000	.00000
Educational Level			
No Formal Education	10	1.0000	.00000
Primary School Education	**24**	**1.1667**	**.38069**
Secondary Education	22	1.0909	.29424
Tertiary	**4**	**1.5000**	**.57735**

[a] it cannot be computed because the standard deviations of both groups are 0

According to the data, participants with 21 to 26 years of age (M = 1.5000, SD = .57735) believed that the PBW collection and trading are compatible with the culture in their setting. Unmarried participants (M = 1.2500, SD = .44233) were associated with the dynamics more than others. The female participants (M = 1.1500, SD = .36162) also believed that the culture is in tandem with the PBW collection and trading. From the data, it could be seen that participants with 5 to 8 family members (M = 1.2308, SD = .42967) and 1 to 4 members (M = 1.1429, SD=.36314) believed that their culture is aligned with the collection and trading of PBW.

This, however, failed to translate to their significant engagement in the collection and trading when one looks at what was recorded under economic dynamics. Participants who practice Christianity (M = 1.1333, SD = .34575) and Islam (M = 1.0714, SD = .26227) connected with the culture compatibility variable. The analysis also established that participants with tertiary education (M = 1.5000, SD = .57735) and primary school education (M = 1.1667, SD = .38069) subscribed to the culture compatibility than those who owned other educational qualifications or no formal education. This result is in agreement with the earlier outcome, which indicates holders of primary and tertiary education qualifications are more attuned to social and economic dynamics. For further understanding of the participants' collection of PBW, specific attitudinal and knowledge variables are examined along with the individual demographics using the Pearson chi-square tests analytical approach. Data in Table 6 show that educational qualification (r = 34.946, df = 9, p < .000), family size (r = 26.682, df = 6, p<.000), religion (r = 10.571, df = 3, p < .014), marital status (r = 19.810, df = 9, p < .019), and age (r = 19.250, df = 9, p < .023) are more associated with collection of PBW.

The significant association of educational qualification with the collection could be more discerned from the fact that the participants need to have adequate knowledge of the availability of PBW generation around them before going for collection. The family size as a factor also indicates that the participants considered the number of their family members, which must be catered for in terms of economic survival before engaging in the collection and trading of PBW.

This position is not quite different for religion, marital status and age association with the collection. In specific terms, these results suggest that the need to ensure the socioeconomic well-being of themselves and others facilitated a knowledge of PBW collection. Data in Table 7 expands our understanding of how the demographics of the participants resonated with their knowledge of collecting PBW.

Table 6
Association between Demographics and Knowledge of Plastic Bottle Waste Collection

Variable	Case	Value	Df	Asymp. Sig. (2-sided)
Gender	40	2.351	3	.503
Age	**38**	**19.250**	**9**	**.023**
Marital Status	**40**	**19.810**	**9**	**.019**
Family Size	**38**	**26.682**	**6**	**.000**
Religion	**40**	**10.571**	**3**	**.014**
Ethnicity	40	8.254	6	.220
Educational Level	**38**	**34.946**	**9**	**.000**
Residential Location	40	17.143	6	.009

Table 7
Dominant Demographic by Knowledge of Plastic Bottle Waste Collection

Age	N	Mean	Standard Deviation
15-20 Years	**4**	**16.0000**	**.00000**
21-26 Years	4	15.5000	.57735
33-38 Years	**16**	**16.0000**	**1.03280**
39 Years Above	**14**	**16.5714**	**1.45255**
Marital Status			
Single	**8**	**16.2500**	**.46291**
Married	**20**	**16.5000**	**1.23544**
Divorced	2	15.0000	.00000
Separated	10	15.8000	1.22927
Family Size			
1-4 Persons	**14**	**16.0000**	**.96077**
5-8 Persons	16	15.7500	1.12546
More than 8 Persons	**8**	**17.5000**	**.53452**
Religion			
Christianity	**20**	**16.2000**	**.89443**
Islam	**20**	**16.2000**	**1.36111**
African Traditional	-	-	-
Educational Level			
No Formal Education	**8**	**17.5000**	**.92582**
Primary School Education	12	15.8333	1.26730
Secondary Education	**14**	**15.8571**	**.66299**
Tertiary	**4**	**16.5000**	**.57735**

According to the data, participants who indicated over 39 years (M = 16.5714, SD = 1.45255), 33-38 years (M = 16.0000, SD = 1.03280) and 15-20 years (M = 16.0000, SD = .0000) as their age associated with the knowledge than others. This finding is in line with the earlier position that those who have the responsibility for taking care of family members engage in the collection and trading of PBW. This is further enhanced by the data that establish that married participants (M = 16.5000, SD = 1.23544) are associated with the knowledge more than others. The connection of the participants who were not married (M = 16.2500, SD = .46291) also resonates with the previous position that the level of unemployment rate influences participation in collection and trading of PBW, which is further enshrined with a significant number of participants of more than 8 people (M = 17.5000, SD = .53452) and 1-4 people (M = 16.0000, SD = .96077) as family members who must be catered for. In terms of religion, participants who practice Islam (M = 16.2000, SD = 1.36111) and Christianity (M = 16.2000, SD = .89443) are linked with the knowledge more than others. Like what was obtained in the previous results, participants who have no formal education (M = 17.5000, SD = .92582) tertiary education (M = 16.5000, SD = .57735) and secondary school education (M = 15.8571, SD = .66299) linked with the

Table 8
Association between Demographics and Plastic Bottle Waste Collection as a Business

Variable	**Case**	**Value**	**Df**	**Asymp. Sig. (2-sided)**
Gender	**62**	**8.449**	**2**	**.015**
Age	**60**	**18.396**	**10**	**.049**
Marital Status	62	12.113	8	.146
Family Size	60	3.941	4	.414
Religion	**60**	**32.005**	**4**	**.000**
Ethnicity	62	.633	4	.959
Educational Level	60	5.937	6	.430
Residential Location	62	3.195	4	.526
Year of Exposure to PBW	62	21.596	18	.250

Table 9
Dominant Demographics by Plastic Bottle Waste Collection as a Business

Age	**N**	**Mean**	**Standard Deviation**
14 and below	**14**	**4.7143**	**.91387**
15-20 Years	6	4.0000	.00000
21-26 Years	4	4.0000	.00000
27-32 Years	2	4.0000	.00000
33-38 Years	**20**	**4.1000**	**.30779**
39 Years Above	14	4.0000	.00000
Gender			
Male	**22**	**4.3636**	**.65795**
Female	40	4.1000	.44144
Religion			
Christianity	30	4.0667	.25371
Islam	**28**	**4.1429**	**.52453**
African Traditional	**2**	**6.0000**	**.00000**

knowledge. This result is surprising when one considers the place of those who lack formal education. From the data, it could be concluded that those who collect PBW are mostly those who have no formal education and university graduates who need to overcome unemployment problems.

While educational qualification and family size dominated the association of demographics with the knowledge of collecting PBW, the data in Table 8 indicate that religion (r = 32.005, df = 4, P < .000) and gender (r = 8.449, df = 2, P < .015), followed by age (r = 18.396, df = 10, P < .049), are better in understanding the place of demographics in knowledge and attitudes of seeing PBW collection as a business. These results are explored further in Table 9, where individual demographics explain the association.

Table 9 entails data that points out the key demographics that connect with the PBW collection as a business. Participants who are 14 years and below (M = 4.7143, SD = .91387) and those within 33-38 years (M = 4.1000, SD = .30779) considered PBW collection as a business than other age categories. Data also indicate that male participants (M = 4.3636, SD = .65795), those practicing African Traditional (M = 6.0000, SD = .00000) and Islam (M = 4.1429, SD = .52453) considered the collection as a business.

11. Discussion of Findings

The substantial correlation between educational qualification, family size, religion, marital status, and age with a sample of PBW demonstrates that participants do not regard socioeconomic issues as a barrier to participation. In terms of knowledge and attitudes toward PBW as a business, particular references to religion, gender, and age demonstrate that these demographics do not prevent participants from perceiving economic and social benefits from engaging in PBW collection for trading. These findings are more understandable when livelihood theory is assumed, which states that cultural environments can produce mindset variations (Baskerville, 2003) as well as entrepreneurial behaviour differences (North, 1990; Shane, 1994), whereas the centre of any business pursuit can construct social relationships and bonds that promote belief rather than opportunism. The social relationships and bonds components of livelihood theory are well-documented by findings that show interpersonal relationships between PBW collectors and traders at various stages of the PBW value chain about financial capital captured by the actors (Wu and Zhang, 2019; Gall et al., 2020). The study reveals that economic dynamics have a greater influence on participants' experiences than social dynamics. This conclusion is consistent with prior research showing that rubbish picking is frequently motivated by economic need, with persons engaging in these activities to supplement their income or make a livelihood in the absence of official work alternatives (Medina, 2010; Solaja, et al., 2023). The study finds that age, married status, gender, family size, religion, and education level are all connected with participants' perceptions of social dynamics during PBW collection. This finding is consistent with existing literature that highlights the importance of socio-demographic characteristics on waste collectors' social contacts, community attitudes, and experiences of marginalization (Medina, 2010; Garcia et al., 2018; Solaja 2019). Similarly, the study discovers that participants' demographics correlate with their perceptions of economic dynamics in PBW gathering and trade. This is consistent with earlier studies emphasizing waste collectors' socioeconomic vulnerabilities and livelihood choices, with demographic characteristics influencing their access to resources, income opportunities, and economic results (Roy, 2010; Ojo et al., 2017). According to the study, participants' demographics have an impact on their cultural perspectives on the compatibility of PBW gathering and trade. While this finding is less prevalent in the literature, it emphasizes the need to take cultural norms and beliefs into account when developing waste management methods, particularly in communities where cultural values may influence individuals' views toward certain activities (Adetola etal., 2018; Khan et al., 2021).

Educational degree, family size, religion, marital status, and age are identified as key factors affecting PBW collection in the study. These findings support earlier research that has highlighted the significance of socioeconomic variables, family obligations, and demographic features in affecting individuals' participation in waste-picking activities (Medina, 2010; Lwasa et al., 2019). According to the study, educational qualifications, family size, religion, gender, and age all have a major impact on knowledge and attitudes concerning PBW collection as a company. This finding is consistent with previous research indicating that numerous socio-demographic characteristics and cultural norms influence people's perceptions of rubbish picking as a realistic economic opportunity (Garcia et al., 2018; Solaja et al., 2023). Younger participants, notably those aged 14 and under, people aged 33 to 38, male participants, and those who practice African Traditional and Islamic religions are more likely to see PBW collection as a business opportunity. This research sheds light on the demographic characteristics of those who see waste picking as a viable business enterprise, which may differ across cultural and socioeconomic contexts.

12. Conclusions

The escalating global challenge of plastic bottle waste is deeply rooted in the pervasive use of plastic bottles, compounded by a troubling societal indifference to proper disposal practices. This environmental crisis, with its far-reaching impact on human well-being and ecological balance, has taken an unexpected turn. Plastic waste, once perceived only as a threat, has now become an unexpected business opportunity for individuals who collect plastic bottles. The study, conducted in the Ijebu region of Ogun State, Nigeria, shed light on the complex interplay of socio-demographic factors that influence plastic bottle waste (PBW) collection. In particular, the study highlights the significant correlation between educational qualification, family size, religion, marital status, age, gender, and place of residence with the practice of collecting plastic bottle waste. These factors emerged as key determinants influencing the attitudes and knowledge of individuals involved in plastic bottle waste collection, highlighting the multifaceted nature of this informal sector. Amidst the environmental challenges posed by plastic pollution, the study shows that waste collectors, who are often marginalized, not only play a crucial role in waste management, but also contribute to a circular economy. Their activity goes beyond simply collecting waste and has evolved into a livelihood that combines environmental awareness and entrepreneurial initiatives. In light of these findings, policy makers should recognize the central role of plastic bottle waste collectors in the broader waste management landscape. The provision of basic support, facilities, and formal recognition for these individuals is essential to promote an inclusive circular economy. This approach addresses not only environmental sustainability issues, but also the socio-economic challenges associated with plastic waste. Given the pressing global problem of plastic pollution, recognizing and empowering those who collect plastic bottles is an important step towards a more sustainable and equitable future.

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Ispitivanje sociodemografskih karakteristika i razumevanje poslovnih faktora među sakupljačima plastičnog otpada u državi Ogun, Nigerija

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Ovaj rad istražuje sociodemografska i ekonomska iskustva sakupljača i trgovaca plastičnim otpadom (PO) u gradu Ijebu-Ode, država Ogun, kroz ankete i produbljene intervjue. Rad koristi teoriju sredstava za život kao kontekst. Istraživanje je pokazalo da su obrazovanje, veličina porodice, religija, bračni status i starost više povezani sa sakupljanjem PO, dok su religija, pol i starost pogodniji za razumevanje znanja i stavova ljudi koji sakupljaju PO radi profita. Civilizacija, moderna kultura i potrošački obrasci, populacija, tehnologija i industrijski rast uticali su na generisanje i sakupljanje otpada za većinu ljudi. Niske stope reciklaže, neefikasne mere odlaganja otpada i nedostatak znanja o reciklaži otpada ometaju sakupljanje komunalnog otpada i razvoj ovog posla. Da bi se poboljšao ekonomski i socijalni položaj sakupljača i trgovaca i smanjio uticaj PO na životnu sredinu, predlaže se izgradnja objekta i donošenje mera za formalizaciju ovog posla.

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Bnaslawa Environmental Parameters Planning Modelling

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ABSTRACT

Global warming, climate change, greenhouse gasses, floods, drought years, and desertification have an impact on the environment. Naturally, the environment of Bnaslawa district (Dashti Hawler) in Erbil City-Iraqi Kurdistan region is affected by the global environmental changes. This research focused on the assessment of environmental parameters, planning, and environmental modelling in Bnaslawa district. A series of site visits, interviews, collection of documented data from directories and literature were conducted for data collection. Environmental factors such as wind direction, topography, water sources, soil type, distance, archeology, esthetics, air pollution, noise pollution, and disease spread were selected. The selected points for environmental planning were landfill, gas factory, slaughterhouse, quarry, cemetery, wastewater treatment plant, green area, animal shelters, industrial area, commercial area, institutional area, and service area. The points for the environmental factors were changed from zero (low impact) to 10 (strong/high impact). The ratio of points and twelve mathematical models for the elements were determined. Based on the scoring and mathematical models, wind direction, topography, water sources, archeology, esthetics, air pollution, noise pollution, and disease spread had an excessive impact on the planning and management of environmental parameters. In contrast, soil type and distance had less influence.

1. Introduction

Erbil is the capital of the Kurdistan Region of Iraq. The population of Erbil province was 2,254,420 in 2022. Erbil province consists of ten districts such as Erbil City Center, Bnaslawa (Dashti Hawler), Khabat, Makhmour, Koya, Shaqlawa, Soran, Ruwuz, Mergsour and Choman (Erbil Governorate, 2021). Each district has a number of sub-districts and villages. Figure 1 shows the Kurdistan Region and the districts in Erbil Province. The increase in population, climate change, refugees, internally displaced persons, economic and political problems have impacted the administration of Erbil province and districts. Water and wastewater management, solid waste, green areas, air pollution and dust storm, landscape and land use change, flooding, foul odors and smoke are common environmental problems related to the planning of Bnaslawa and other districts in Erbil province. In Bnaslawa district and other districts and sub-districts of Erbil province, there is generally no scientific and studied master plan and environmental planning. To date, there is no systematic and recognized study on the environmental problems and planning of Bnaslawa District in the literature. Accordingly, the aim of this study was to investigate the environmental parameters, planning and environmental modeling in Bnaslawa

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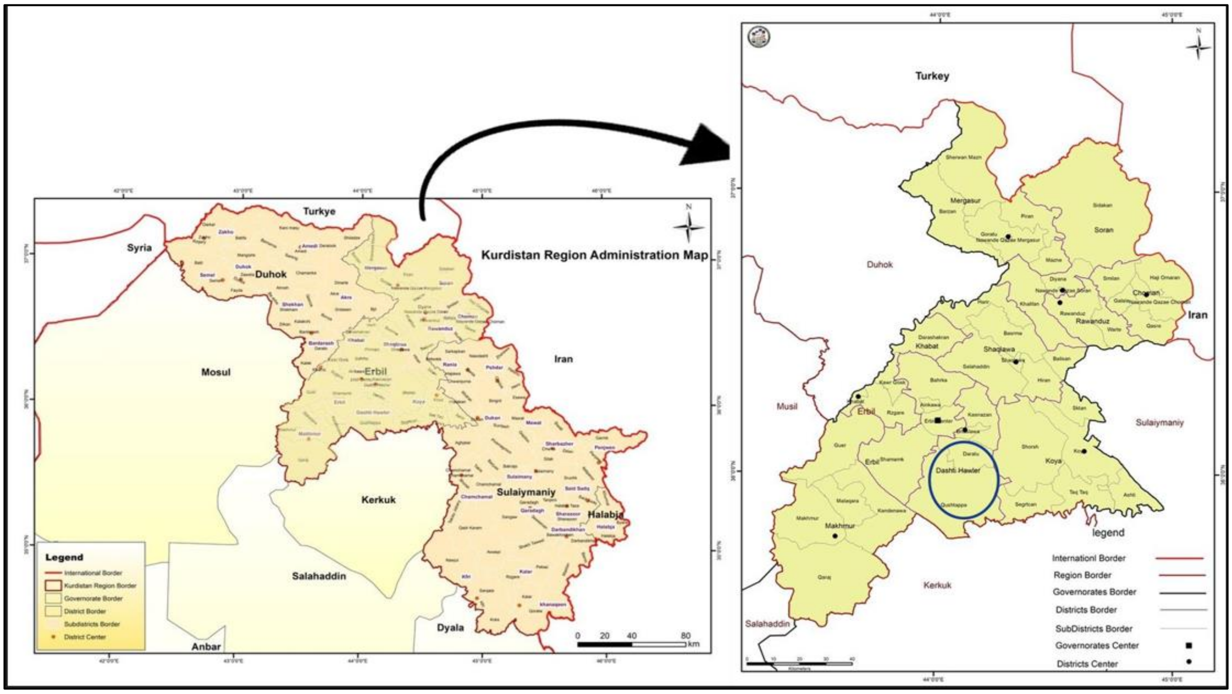


Figure 1. Map of Kurdistan Region and Districts of Erbil Province (KRSO, 2022)

District. So far, this type of study has not been conducted for Bnaslawa District and other districts in Erbil province.

2. Material and Methods

The satellite images of the city of Erbil and the district of Bnaslawa are shown in Figure 2. Bnalawa district is located in the southeast of Erbil city center, Figures 1 and 2, about 10 km from Erbil city. Before 1987, Bnaslawa was a village and was called Great or Big Bnasalawa. Before 1987, the village of Great Bnaslawa was destroyed/burned several times. In 1987, however, the village was completely destroyed and replaced by Bnaslawa Camp. In 1997, Bnaslawa became a sub-district.

In 2002, Bnaslawa was converted into a district and given the name Dashti Hawler (Erbil Plain) or Bnaslwa District. Currently, Bnaslawa District has three sub-districts (Kasnazan, Daratoo and Qushtapa) with 112 villages. The coordinates are 44° 0’ 0" E to 44° 15’ 0" and 35° 45’ 0" to 36° 15’ 0", respectively (Figure 1).

a)

b)

Figure 2. Satellite image of Bnaslawa (Dashti Hawler) District (a,b)

Both qualitative and quantitative research methods were used. Several site visits were made to the Bnaslawa district on March 2, 2021, October 19, 2021, November 3, 2021, January 13, 2022, January 16, 2022, May 3, 2022, April 22, 2023 and February 15, 2024. Direct visits were made to the Bnaslawa district office, the area surrounding the Bnaslawa district, the slaughterhouse, the water shed, the gas factory, the city administration, the water authority and the agricultural authority.

Environmental parameters such as weather, precipitation and flooding, water supply and wastewater, solid waste, green areas, air pollution, land cover and land use were examined. Environmental planning was also examined. The assessment of environmental parameters and planning was based on published documents and standards (Singh and Singh, 2004; Davis and Cornwell, 2008; Aziz 2020).

3. Results and Discussions

3.1. Characteristics of the Bnaslawa District

The characteristics of the district of Bnaslawa are listed in Table 1. The data were obtained through several site visits, interviews and published documents. Residential houses are usually built of concrete blocks with cement plaster outside and gypsum plaster inside. Sometimes other finishing materials such as ceramic tiles, marble and false ceilings are also used.

Sand and gravel pits are available inside the water sheds. Paving and simple concrete are used for the roads. The Bnaslawa district has a health center, a youth center, schools, the police department, a bank, the city administration, the water authority, the agricultural authority, local markets and supermarkets, the land registry and sports fields. The lifestyle of the families ranges from middle to poor. A large proportion of the inhabitants of Bnaslawa travel to the city of Erbil during the day to work, shop and deal with official business. The district of Bnaslawa is surrounded by newly built neighborhoods and agricultural areas. Modern supermarkets, parks and stores are available in Bnaslawa.

3.2. Environmental Parameters

The information in this section was obtained through site visits, interviews and data collection. This section covers watersheds, waste management, water supply, wastewater, air pollution, land cover and land use.

3.2.1. Watershed

The main water reservoir is located in the northern part of Bnaslawa district, Figures 3 and 4. The watershed of Bnaslawa, locally called Basti Mzoran. This watershed carries runoff during the rainy season (i.e. from October to April). On the other hand, the watershed remains dry during the non-rainy seasons (i.e. May to September). A number of quarries observed during the site visits utilize the watershed for aggregate (sand and gravel) extraction. Some areas for sheep, goats and cows were identified within the catchment. Indiscriminate dumping of waste in the watershed has been observed. Climate change, drought years, projects and the expansion of residential areas around the district have had an impact on the reduction of runoff compared to the 1980s and 1990s.

Table 1
Characteristics of Bnaslawa District (Bnaslawa (Dashti Hawler) District (2021), site visit and Interview)

No.	Item	Unit	Value	Notes
1	Area	km^2	29	Area of district centre
2	Sub-districts	No.	3	Kasnazan, Daratwoo, and Qushtapa
3	Villages	No.	112	Bnaslawa District (4 Villages), Kasnazan Sub-District (32 Villages), Daratoo Sub-District (19 Villages), and Qushtapa Sub-District (57 Villages)
4	Population	No.	130,548	47,571 Men (36.44 %), 47804 Women (36.62 %), and 35173 (26.94 %) Children
5	Constructed houses	No.	33,000	14,000 normal house (each 200 m^2) +19,000 houses (each 100 m^2) for district centre
6	Green area	Donum	23	Namran and Hawar Parks at district centre
7	Sheep	No.	43,743	
8	Goat	No.	18,788	
9	Cow	No.	900	
19	Calf	No.	1,344	
11	Agriculture	-	-	Wheat, barley, corn, vegetables, and fruits.
12	Dairy products	-	-	Yogurt, cheese, butter, cream, and milk

Figure 3. Water shed of Bnaslawa District (Site visit on March 2, 2021)

a)

b)

c)

Figure 4. Watershed and flood of Bnaslawa District (Visted on: a) January 13, 2022, b) January 16, 2022 and c) February 15, 2024

3.2.2. Solid Waste Management

Solid waste consists of food, plastic, cardboard, metals, glass, trees and leaves, garden waste and clothing. All types of waste are mixed at the collection points and collected by the municipality's vehicles. Some of the recyclable waste, such as cardboard, plastic and metals, is collected by citizens and sold at the designated points. Later, the recyclable materials are used as raw materials (Aziz et al., 2023b). The population of the Bnaslawa district is estimated at 100,000 people (Bnaslawa (Dashti Hawler) District, 2021). Based on the published work, the average solid waste generation rate is 1 kg/capita/day (Aziz, 2023). Consequently, the amount of solid waste produced is 100,000 kg (100 tons). The collected solid waste is disposed in Erbil landfill near Kani Qrzhala sub-district. It is proposed to separate organic and non-organic waste for the production of composite materials (Aziz et al., 2018). On the other hand, separating recyclable materials from others leads to a reduction in waste and becomes an income for the community (Aziz et al., 2023b).

3.2.3 Water Supply

Groundwater is the main source of water supply in the Bnaslawa district. A number of artesian wells supply the municipality with drinking water. The water is pumped directly into the water distribution system. There is no central water reservoir or elevated tank in the water supply system. The information was collected through direct interviews with the Directorate of Water in the Bnaslawa district. Figure 5 shows the Bnaslawa District Water Directorate. The water provided is used for domestic use, irrigation of green areas and washing. Based on the research published by Hawez et al. (2020), the quality of groundwater can be utilized for drinking water and other purposes. It is proposed to apply a sustainable water supply system using treated surface water from the Greater Zab River or Gomaspan Dam instead of groundwater.

Figure 5. Directorate of Water in Bnaslawa District (Visited on October 19, 2021)

3.2.4. Wastewater

After consumers have used the water provided, it becomes wastewater. In some areas, gray wastewater is channeled through the sewage system or transported through unlined canals outside the Bnaslawa district in the south, Figure 6. Later, the channeled wastewater spreads in the environment or enters the Kornish valley, which is outside the 120 m road in the city of Erbil. In the rainy season, gray wastewater mixes with surface runoff and the mixed wastewater enters the Kornish Valley (Aziz et al., 2023c).

To date, there is no wastewater treatment plant (WWTP) in the Bnaslawa district. The produced wastewater from Bnaslawa district can be considered as weak wastewater and can be treated in wetlands and aerated lagoons (Aziz, 2020; Aziz et al., 2023a).

In some areas, there are sewer systems with different lengths and different concrete sewer sizes of 0.75 m, 0.9 m, 1.0 m and 1.2 m. In addition, in other zones, box sewers with dimensions of 1.0 m x 1.2 m, 1.5 m x 1.5 m, 2 m x 2 m and 2 m x 2.5 m are available in different lengths. Black wastewater is normally treated in cesspools. About 2 % of black wastewater is illegally connected to the sewage system.

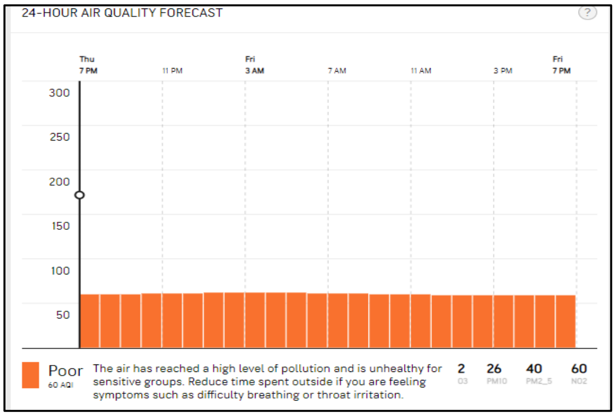
a)

b)

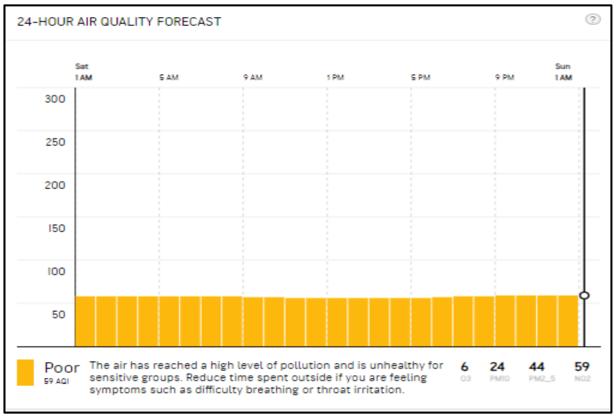
Figure 6. Wastewater conveying by sewerage system and unlined channel (Visited on November 3, 2021)

3.2.5. Air Pollution

The district of Bnaslawa is located far from the city center of Erbil. It is surrounded by a plain to the east and south. Figure 7 illustrates the air quality index (AQI) in the Bnaslawa district. The reported AQI was 60, which is considered a poor level. The expansion of the residential area, the increase in the number of cars and population, and the decrease in green spaces and plains have affected the AQI in the Bnaslawa district. The values for ozone, particulate matter (PM)10, PM2.5 and NO_2 were 2-6, 24-26, 40-44 and 59-60 mg/L, respectively. In general, the air is polluted, unhealthy and impairs breathing. It is proposed to reduce air pollution by increasing green spaces.



a)



b)

Figure 7. AQI for Bnaslwana District a) Date: April 4, 2022 and b) Date: October 6, 2023 (https://www.accuweather.com/en/iq/bnaslawa/506220/air-quality-index/506220)

3.2.6. Land Cover and Land Use (Green area)

The wheat and barley planted in the Bnaslawa district are a hundred years old, Figure 8, as are tomatoes, cucumbers, melons, watermelons, onions, fruit and vegetables. Before 1958 there was a very nice orchard in the village of Bnaslawa. There was a spring and a water channel at that time. Geologically, the soil layers consist of earth and sandy gravel. Nowadays, due to investment projects and the expansion of residential areas, some of the soil is being converted into concrete, tiles and pavement, resulting in a decrease in agricultural land and an increase in surface runoff (Aziz et al., 2023c). From a sustainability perspective, agricultural land should be preserved and protected for future generations (Aziz and Mustafa, 2022). Figure 9 shows the Nice Land Park in the district of Bnaslawa.

Table 2
Bnaslawa Environmental Planning Modelling

No.	Items	Environmental Factors Weight (0 to 10)										Total
		Wind direction (WD)	Topography (T)	Water Source (WS)	Soil Type (ST)	Distance (D)	Archeology (Ar)	Aesthetic (Ae)	Air pollution (AP)	Noise Pollution (NP)	Disease propagation (DP)	
	Dump site (DS) Points	9	7	8	9	6	9	8	9	8	9	82
1	DS Ratio of points	0.11	0.09	0.10	0.11	0.07	0.11	0.10	0.11	0.10	0.11	1.00
	Equation: DS=	0.11 WD + 0.09T+0.1 WS + 0.11 ST + 0.07 D+ 0.09 Ar + 0.1 As +0.11AP+ 0.1 NP + 0.11DP										
	Domestic Gas Factory (DGF) points	10	4	5	1	9	9	8	10	10	9	75
2	DGF ratio of points	0.13	0.05	0.07	0.01	0.12	0.12	0.11	0.13	0.13	0.12	1.00
	Equation: DGF=	0.13 WD + 0.05T+0.07 WS + 0.01 ST + 0.12 D+ 0.12 Ar + 0.11 Ae +0.13AP+ 0.13 NP + 0.12DP										
	Slaughter House (SH) Points	10	2	9	0	9	8	10	10	9	10	77
3	SH Ratio of points	0.13	0.03	0.12	0	0.12	0.10	0.13	0.13	0.12	0.13	1.00
	Equation: SH=	0.11 WD + 0.03T+0.12 WS + 0.0 ST + 0.12 D+ 0.1 Ar + 0.13 Ae +0.13AP+ 0.12 NP + 0.13DP										
	Quarry (Qu) Points	5	9	8	9	7	10	5	8	10	0	71
4	Qu Ratio of points	0.07	0.13	0.11	0.13	0.10	0.14	0.07	0.11	0.14	0	1.00
	Equation: Qu=	0.07 WD + 0.13T+0.11 WS + 0.13ST + 0.10 D+ 0.14Ar + 0.07 Ae +0.11AP+ 0.14 NP + 0 DP										
	Cemetery (Ce) Points	2	8	8	10	9	10	8	3	8	5	71
5	Ce Ratio of points	0.03	0.11	0.11	0.14	0.13	0.14	0.11	0.04	0.11	0.07	1.00
	Equation: Ce=	0.03 WD + 0.11T+0.11 WS + 0.14ST + 0.13 D+ 0.14Ar + 0.11 Ae +0.04AP+ 0.11 NP + 0.07 DP										
	WWTP Points	10	9	9	3	7	8	9	9	8	9	81
6	WWTP Ratio of points	0.12	0.11	0.11	0.04	0.09	0.10	0.11	0.11	0.10	0.11	1.00
	Equation: WWTP=	0.12 WD + 0.11T+0.11 WS + 0.04ST + 0.09 D+ 0.1Ar + 0.11 Ae +0.11AP+ 0.10 NP + 0.11 DP										
	Green Area (GA) Points	8	7	9	9	8	7	10	2	5	0	65
7	GA Ratio of points	0.12	0.11	0.14	0.14	0.12	0.11	0.15	0.03	0.08	0	1.00
	Equation: GA=	0.12 WD + 0.11T+0.14 WS + 0.14ST + 0.12 D+ 0.11Ar + 0.15 Ae +0.03AP+ 0.08 NP + 0.0 DP										
	Animal Shelters (AS) Points	10	5	8	6	7	9	10	8	8	9	80
8	AS Ratio of points	0.13	0.06	0.10	0.08	0.09	0.11	0.13	0.10	0.10	0.11	1.00
	Equation: AS=	0.13 WD + 0.06T+0.10 WS + 0.08ST + 0.09 D+ 0.11Ar + 0.13 Ae +0.10AP+ 0.10 NP + 0.11 DP										
	Industrial Area (IA) Points	10	5	8	6	7	9	10	8	8	9	80
9	IA Ratio of points	0.13	0.06	0.10	0.08	0.09	0.11	0.13	0.10	0.10	0.11	1.00
	Equation: IA=	0.13 WD + 0.06T+0.10 WS + 0.08ST + 0.09 D+ 0.11Ar + 0.13 Ae +0.10AP+ 0.10 NP + 0.11 DP										
	Commercial Area (CA) Points	5	5	6	2	9	8	5	8	10	6	64
10	CA Ratio of points	0.08	0.08	0.09	0.03	0.14	0.13	0.08	0.13	0.16	0.09	1.00
	Equation: CA=	0.08 WD + 0.08T+0.09 WS + 0.03ST + 0.14 D+ 0.13Ar + 0.08 Ae +0.13AP+ 0.16 NP + 0.09 DP										
	Institutional Area (InA) Points	4	7	5	3	9	8	3	4	9	4	56
11	InA Ratio of points	0.07	0.13	0.09	0.05	0.16	0.14	0.05	0.07	0.16	0.07	1.00
	Equation: InA=	0.07 WD + 0.13T+0.09 WS + 0.05ST + 0.16 D+ 0.14Ar + 0.05 Ae +0.07AP+ 0.16 NP + 0.07 DP										
	Services Area (SA) Points	6	7	8	5	8	9	2	5	8	5	63
12	SA Ratio of points	0.10	0.11	0.13	0.08	0.13	0.14	0.03	0.08	0.13	0.08	1.00
	Equation: SA=	0.10 WD + 0.11T+0.13 WS + 0.08ST + 0.13 D+ 0.14Ar + 0.03 Ae +0.08AP+ 0.13 NP + 0.08 DP										

Figure 8. Natural Environment- Small Bnaslwa Village (Site Visit on April 22, 2023)

Figure 9. Nice Land Park- Bnaslawa District

3.3. Environmental Planning and Modelling

Normally, environmental planning consists of current evaluation, vision and implementation. Present assessment of the environmental factors in Bnaslawa District described in the previous section. The vision is to enhance the environmental conditions in the studied area according to the standards. Implementation of the suggested ideas is related to decision maker's policy, political and financial issues. The author presented a table for suggestion of a new location for any item which effect the environment, Table 2. The weight for each item is given in the table as well. The weights for the environmental factors were selected according to the impact on the environment and based on the background. Twelve items for environmental planning were chosen as given in Table 2. The selected items were solid waste dumpsite, domestic gas factory, slaughterhouse, quarry, cemetery, WWTP, green area, animal shelters, industrial area, commercial area, institutional area, and services area. For each item, environmental factors such as wind direction, topography, water sources, soil type, distance, archeology, aesthetic, air pollution, noise pollution, and disease propagation were studied. Environmental points varied from zero (low impact) to 10 (strong/high impact). Ratio of points and equation for each item were found. Twelve mathematical models for the items were derived, Table 2. It can be noticed that wind direction, topography, water sources, archeology, aesthetic, air pollution, noise pollution, and disease spread had great impact on the environmental planning and management items. While, soil type and distance had less influence.

4. Conclusions

Deficiency was identified in environmental planning and management in Bnaslwa District. Proper waste management and treatment is recommended for Bnaslawa District. Main storage water tanks are lacking in the water supply system and a sustainable solution for water supply is essential. Adequate collection, transportation and treatment of the generated wastewater is not possible. Therefore, economical and practical/simple treatment methods such as aerated lagoons and wetlands are recommended for wastewater treatment. AQI levels were poor which is an indicator of air pollution in the district. Land cover and land use were changed resulting in reduction of agricultural land and increase in surface runoff. It is recommended that some areas such as cemeteries, slaughterhouses, gas factories, industrial areas, quarries, tile and marble exhibitions and animal shelters be re-planned and allocated. According to the assessment and mathematical models, wind direction, topography, water sources, archeology, esthetics, air pollution, noise pollution and disease spread had a huge impact on the planning and management of environmental parameters. Soil type and distance had less impact.

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Modeliranje planiranja ekoloških parametara za distrikt Bnaslava

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Planiranje

I Z V O D

Globalno zagrevanje, klimatske promene, gasovi staklene bašte, poplave, suša i dezertifikacija imaju uticaj na životnu sredinu. Prirodno, okruženje distrikta Bnaslawa (Dashti Hawler) u gradu Erbil, region iračkog Kurdistana, pogođeno je globalnim ekološkim promenama. Ovo istraživanje je fokusirano na procenu ekoloških parametara, planiranje i modeliranje okruženja u ovom distriktu. Za prikupljanje podataka sproveden je niz terenskih poseta, intervjua, te prikupljanje dokumentovanih podataka iz direktorija i literature. Izabrani su ekološki faktori kao što su pravac vetra, topografija, izvori vode, tip zemljišta, udaljenost, arheologija, estetika, zagađenje vazduha, buka i širenje bolesti. Izabrane tačke za ekološko planiranje bile su deponija, fabrika, klaonica, kamenolom, groblje, postrojenje za preradu otpadnih voda, zelena površina, azil za životinje, industrijska zona, komercijalna zona, institucionalna zona i uslužna zona. Vrednosti za ekološke faktore su varirale od nule (nizak uticaj) do 10 (jak/visok uticaj). Odnos bodova i dvanaest matematičkih modela za elemente su utvrđeni. Na osnovu bodovanja i matematičkih modela, pravac vetra, topografija, izvori vode, arheologija, estetika, zagađenje vazduha, buka i širenje bolesti imali su izrazit uticaj na planiranje i upravljanje ekološkim parametrima. Nasuprot tome, tip zemljišta i udaljenost su imali manji uticaj.

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Application of Artificial Neural Network in the Modeling and Optimization of Volatile Acid from Anaerobic Digestion of Biomass

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ABSTRACT

Artificial neural networks (ANNs) and Brute Force algorithms (BF) are two of the most common and simplest techniques for modeling non-linear problems and linear search for an element. Very large data sets are actually compiled and fed into the ANN. An algorithm is run that iteratively makes billions of small adjustments to the weights and biases of millions of nodes. In this paper pilot-scale fermentation tests are carried out with mixtures of sewage sludge and food residues to investigate different process parameters that influence fermentation yields. A machine learning approach is used for data management and the development of a model capable of correlating process performance based on different inputs (operating parameters). To simulate the digester operation and estimate the Volatile Fatty Acid (VFA) outputs, a multi-layer ANN model with two hidden layers is developed. The ANN and BF are used to simulate and optimize the VFA from anaerobic digestion.

1. Introduction

Anthropogenic climate change, caused in various ways by the emission of greenhouse gasses, is the main reason for this catastrophe. This has obligated the government agencies and scientific communities to legislate and develop alternative solutions to overcome the aforementioned breakdown. Moreover, amidst existing options, biomass and biofuels as its main products seem to be a viable path to a sustainable development (Atadashi et al., 2012). As a result, researchers are investigating the use of renewable biomass to produce materials, fuels, and chemicals. In recent years, biomass has become a popular renewable source for energy production (Tilman et al., 2009). The use of biomass for energy production has increased in the United States by more than 60 % between 2003 and 2013 (U.S. Energy Information Administration, 2014).

Amongst different methods to produce biofuels (e.g., biogas, bioalcohols, biodiesel, etc.) from biomass, anaerobic digestion (AD) of biomass for methane production has received a lot of attention (Pilli et al., 2015). AD is a biological process in which a vast amount of biodegradable organic materials can be reduced to produce biogas (containing methane, carbon dioxide as well as traces of other gases, including nitrogen, hydrogen and hydrogen sulfide) with the help of microorganisms under anaerobic conditions. Biomass conversion into biogas takes place in four successive biological stages, that is to say hydrolysis, acidogenesis, acetogenesis and methanogenesis.

However, recent studies suggest terminating the AD

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process before the fourth stage to produce volatile fatty acids (VFAs), hydrogen (which is a clean fuel of high value) and carbon dioxide (Chang et al., 2010). In addition, unlike biogas, the storage and transfer of VFAs are much safer and easier, and they have a higher economic value than biogas.

In science and engineering, artificial neural networks (ANN) are used to solve a variety of problems, especially in areas where traditional modeling methods fail. A well-trained ANN, a data processing system inspired by biological neural systems, can be used as a predictive model for a specific application. An ANN's prediction capacity is determined by experimental data training and subsequent independent data validation. As new data becomes available, an ANN can relearn to improve its performance (Ghobadian et al., 2009).

A neural network is made up of three layers: an input layer, a few hidden layers, and an output layer. Each layer has a set number of neurons or nodes that are connected to each other. Each neuron is connected to the others via communication links and connection weights. On the linking weights, the signals flow through neurons. Each neuron receives various inputs from other neurons based on their connection weights and generates an output signal that can be generated by other neurons as well (Kalogirou, 2001; Kurt et al., 2007).

The network was subjected to two procedures to create an ANN model: Training and Testing. The network is trained to estimate the output values based on the input data during training. The network is used to estimate an output and is tested to estimate or store training data.

2. The role of ANN in anaerobic digestion systems

Neural networks have been utilized in anaerobic digestion systems for the analysis of trace gases (Strik et al., 2005), regulation of $NaHCO_3$ buffer addition, management of digester start-up and recovery, as well as for advanced control and forecasting of biogas production (Guwy et al., 1997; Holubar et al., 2002; Holubar et al., 2003).

In the realm of estimating, predicting and modeling statistical and analytical data, Artificial Neural Networks (ANN) stand out as a potent modeling tool that offers a swift and cost-efficient alternative to conventional analytical techniques (Betiku et al., 2015; Nguyen et al., 2020).

It is worth noting that Artificial Neural Networks demonstrate superior accuracy compared to the Response Surface Method (RSM) in forecasting higher biogas yields (Dahunsi et al., 2016).

Some studies have used neural networks to forecast how much biogas can be made from different substances in order to understand their characteristics and makeup (Gueguim et al., 2012; Beltramo et al., 2016; Verdaguer et al., 2016). Holubar and his team of researchers (Holubar et al., 2002) used different types of neural network models to understand and control how methane gas was made in tanks that did not have oxygen and were constantly stirred. They were studying how the amount of waste being put into the tanks affected the production of methane.

It was found that the new models could accurately predict the amount and type of gas produced by the reactors. Strik and colleagues (Strik et al., 2005) made a model to predict certain gases like hydrogen sulfide and ammonia using ANN. The model could accurately predict the trace gases even when conditions were changing.

Ghatak and other researchers in 2018 (Ghatak et al., 2018) used a neural network model to guess how biogas production changes at different temperatures. Scientists also use neural network to guess how much methane will be produced in anaerobic digestion which helps them avoid sudden increases in production and increasing efficiency, using information from the process as it happens (Holubar et al., 2002; Abu et al., 2010).

Temperature, acidity, waste chemicals, organic compounds, alkaline substances, solid particles and gas production are the main factors used as input data in ANN models (Holubar et al., 2002; Abu et al., 2010; Yetilmezsoy et al., 2013). Ozkaya and colleagues (Ozkaya et al., 2007) presented ANN models for foreseeing the methane division in landfill gas from anaerobic absorption from field-scale landfill bioreactors at the Odayeri Clean Landfill, Turkey.

The neural network models' performance evaluation indicated that the network output closely matched the corresponding target, yielding correlation coefficient of 0.951 and 0.957 as well as mean squared errors (MSE) of 0.00263 and 0.00250 for the predicted CH_4 fraction in the operation with leachate recirculation and the operation without leachate recirculation, respectively.

Umar Alfa and colleagues (Umar et al., 2024) demonstrated the efficacy of various machine learning algorithms in predicting volatile fatty acid (VFA) levels in the manufacturing process involving primary and secondary sludge. The models achieved a precise fit, boasting an ideal coefficient of determination of 1.0 during training and a respectable correlation coefficient of 0.902 during testing, indicating robust generalization capabilities.

Abu Qdais and colleagues (Abu et al., 2010) gathered operational data from a plant over a 177-day period to investigate the impact of digester operational parameters, including temperature (T), total solids (TS), total volatile solids (TVS), and pH, on biogas production. The study utilized an artificial neural network (ANN) model in conjunction with a genetic algorithm to optimize methane production, resulting in an optimal methane yield of 77 %, surpassing the maximum value of 70.1 % recorded in the plant's records. The model demonstrated a correlation coefficient of 0.87 and a performance mean squared error (MSE) of $6 \cdot 10^{-5}$.

3. Methods

3.1. Data preparation

The provided dataset consists of nine independent experiments, five of which are without pH control and thermal treatment, two with thermal treatment, one with pH control and one with both pH control and thermal treatment. Each experiment includes rows of seven input variables (Organic Loading Rate, Hydraulic Retention Time, temperature, sludge, food waste, day and pH) and the corresponding output values of nine Volatile Fatty Acids (acetic, propionic, isobutyric, butyric, isovaleric, valeric, isocaproic, caproic and heptanoic) as well as soluble chemical oxygen demand (CODsol) and the ratio of the total VFA to CODsol. Table 1 summarizes the operating conditions of all nine Continuous stirred-tank reactor (CSTR) runs; the data reported in this table represents the minimum and maximum values (for OLR and pH), the exact data (usually fixed in a single CSTR run, for waste activated sludge (WAS) and Organic Fraction of Municipal Solid Waste (OFMSW) content, HRT and T), and the application (true) or not (false) for the thermal pretreatment or pH-control strategy.

At the beginning rows with missing values are removed. Because of the scarcity of the available data and increasing the accuracy of the model that will be presented later, OLR, pH and VFA/CODsol ratio were interpolated as a function of day individually for each experiment using a cubic spline, as illustrated in Figure 1. The other inputs such as temperature, HRT, WAS and OFMSW content were kept constant during each process so there was no need to interpolate them. It should be noted that since the study was carried out using a semi-continuous fermentation reactor, it is expected that the interpolated data are fairly accurate

Table 1
Summary of operating conditions with (true) and without (false) pH control and thermal treatment for all the nine CSTR runs

Experiment number	pH control	Thermal pretreatment	OLR ([min, max])	HRT	T°C	WAS content (V/V, %)	OFMSW content (V/V, %)	pH ([min, max])
1	FALSE	FALSE	[12.5,17]	5	55	60	40	[4.6, 6.2]
2	FALSE	FALSE	[8.5, 13]	6	55	70	30	[5, 5.8]
3	FALSE	FALSE	[8, 13]	6	42	70	30	[5.3, 6]
4	FALSE	FALSE	[8, 12.5]	6	37	70	30	[4.9, 6]
5	FALSE	FALSE	[16.5,20]	5	55	50	50	[4.3, 5.1]
6	FALSE	TRUE	[7, 13.5]	6	37	70	30	[5, 6]
7	FALSE	TRUE	[7.5, 11]	6	25	70	30	[5.5,6.3]
8	TRUE	FALSE	[8, 14]	5	37	70	30	[6.8, 7.7]
9	TRUE	TRUE	[7, 14]	5	37	70	30	[8.3, 9.3]

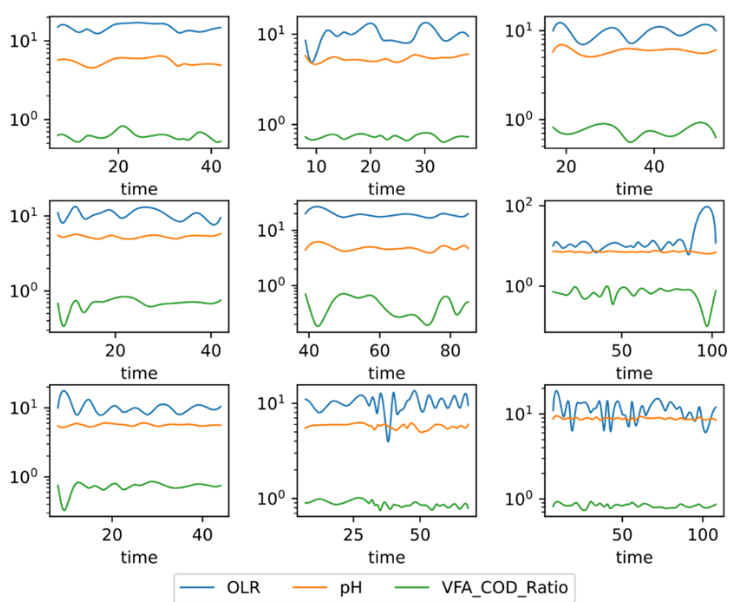

Figure 1. Interpolated data

3.2. Building a regression multilayer perceptron

A multilayer perceptron (MLP) is a feedforward neural network (FNN). An FNN is an artificial neural network (ANN) in which the signal moves only in one direction (from the inputs to the outputs). An ANN is a computational model inspired by the networks of biological neurons of the human brain. A biological neuron or nerve cell is a cell found in animal brains. It consists of a cell body containing the nucleus, dendrites and a single axon. The axon splits off into multiple branches called telodendria, and at the tip of these branches are structures called synapses, which are connected to the dendrites or cell bodies of other neurons.

A perceptron is made up of a single layer of Threshold logic unit (TLUs) (Figure 2), each connected to all of the inputs. A fully connected layer, also known as a dense layer, is one in which all of the neurons are connected to every neuron in the previous layer (i.e., its input neurons).

The perceptron's inputs are fed to input neurons, which are special passthrough neurons that output any input they are fed. The input layer is made up of all the input neurons.

The MLP presented here consists of an input layer with seven nodes, including HRT, temperature, sludge/food waste ratio, OLR, pH and two binary nodes indicating if a row of the dataset belongs to an experiment carried out with or without pH control and thermal treatment, two hidden layers with 256 and 224 nodes and one output layer with only one node representing the ratio of VFA to CODSOL (Figure 3).

The number of nodes in each hidden layer was determined using KerasTuner library. Both hidden layers use ReLU activation function. The model uses the mean squared error (MSE) as the loss function during the training. In addition, one third of the whole interpolated dataset were used for testing (two third for train set), and one third of the train set were used for validation.

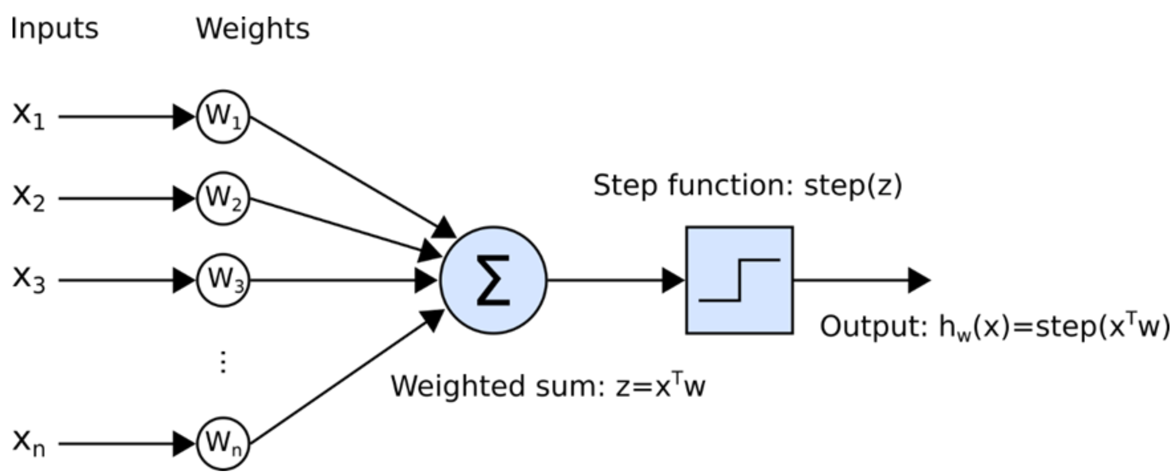

Figure 2. Threshold logic unit

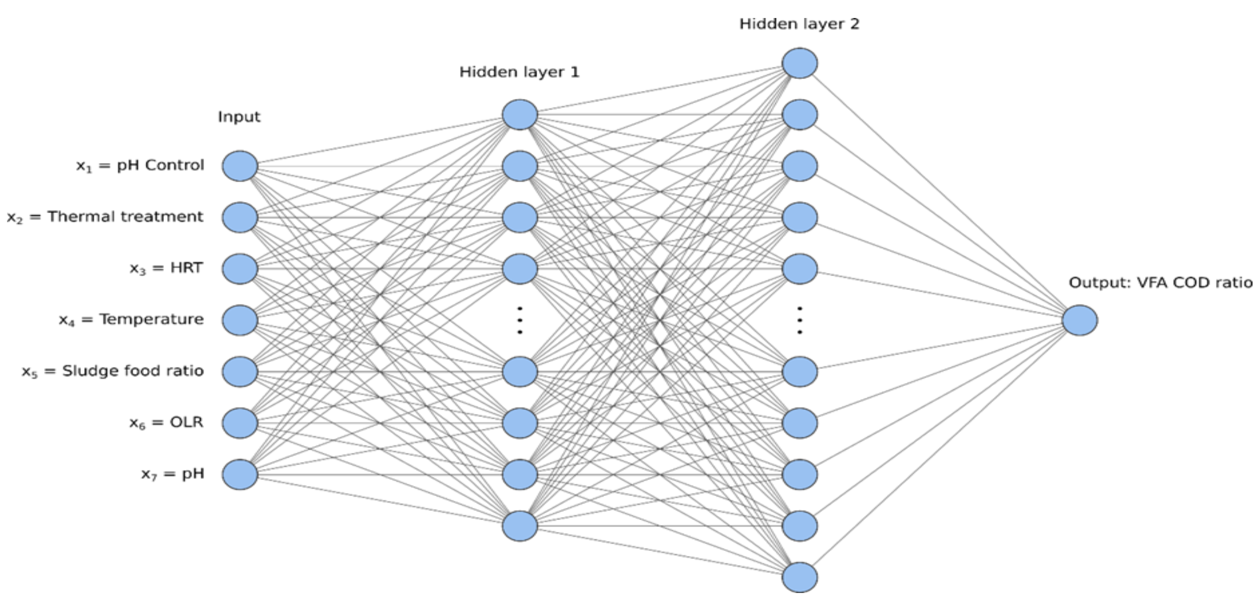

Figure 3. The regression MLP

4. Results and discussion

After compiling (training) the model using the MSE loss and fitting it on the training set for 10.000 epochs (number of complete passes of the training algorithm through the training set) and evaluating it on the validation set (to provide an unbiased evaluation of the model fit on the training set during tuning the internal parameters of the model), it has been get an MSE of about 0.0018 during training (Figure 4) and 0.0027 during evaluation using the test set. In other words, the model could predict the unseen data (test set) with the MSE of about 0.0027. Also, Figure 5 and Figure 6 illustrate that the model predicted the test set fairly accurately.

Figure 5 shows all the VFA/CODSOL ratio collected in all the nine CSTR runs, without any trend but just a sequence of data experimentally obtained (blue line). The predicted VFA/CODSOL values (pink dots; by the model) are often overlapped the real data (experimentally obtained).

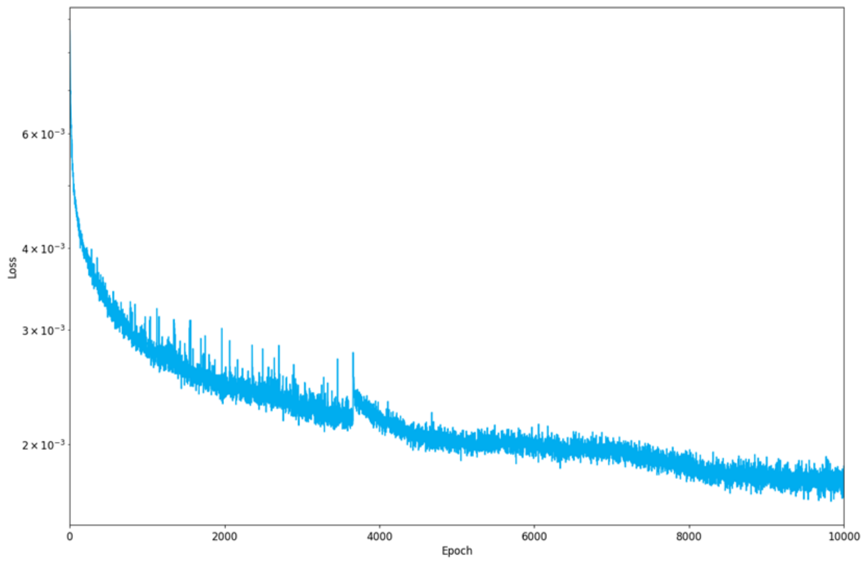

Figure 4. Learning curve: the mean training loss measured over each epoch

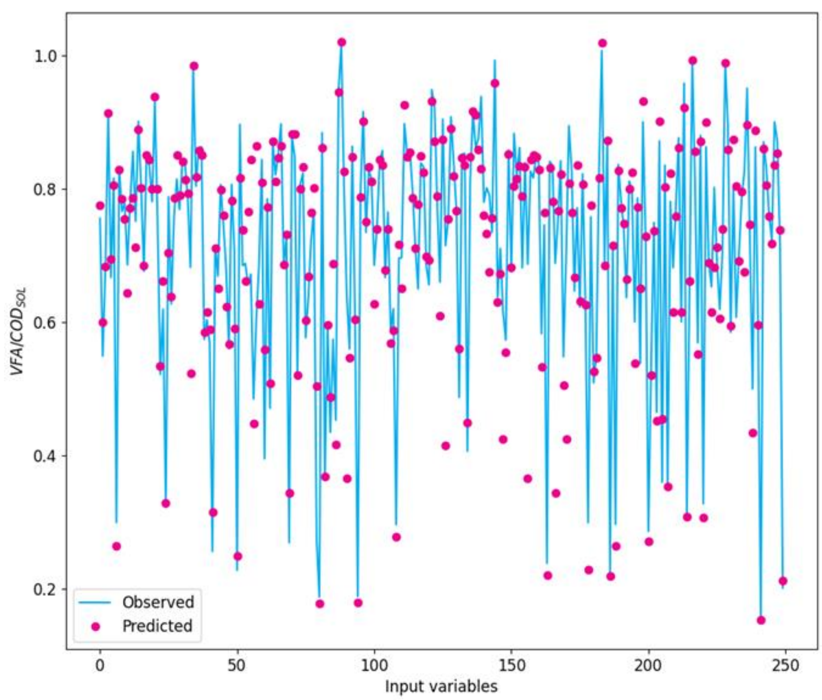

Figure 5. Actual versus predicted VFA/CODSOL values for the first 250 rows of the test set

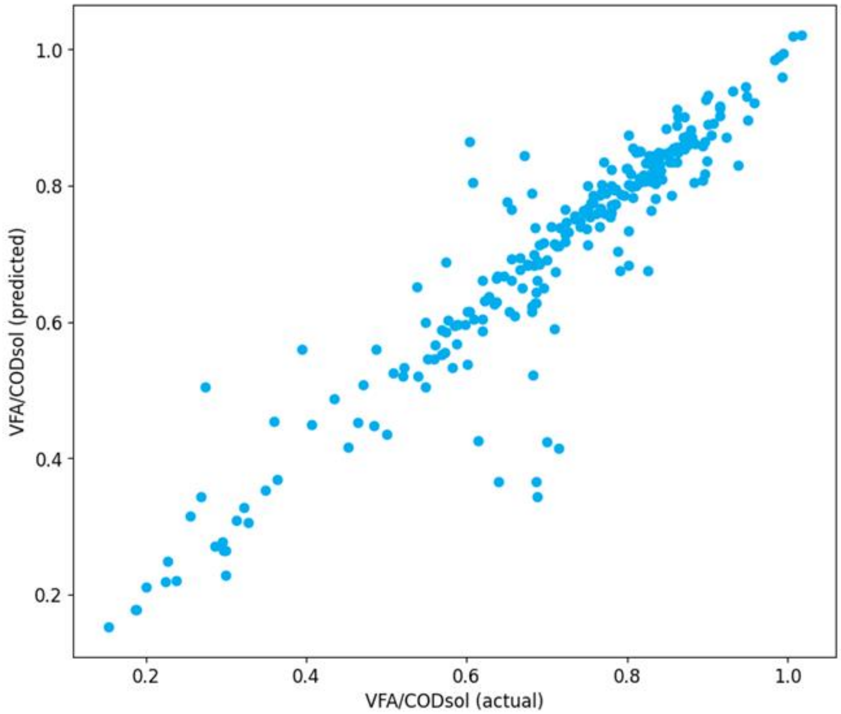

Figure 6. Actual versus predicted VFA/CODSOL values for the first 250 rows of the test set

In order to obtain the optimal values of VFA/CODSOL ratio in the acidogenic fermentation process as a function of operating parameters, a simple brute-force search was carried out using the values' ranges provided in TABLE 2. The highest experimental value of VFA/CODSOL (as output) in the provided dataset was 0.99, as ideal value to achieve. By considering all the past experiments, the highest VFA/CODSOL ratio value (0.86) was obtained in a CSTR run performed by applying thermal treatment to the feedstock, without pH control and with the corresponding input values of OLR of 8.0 kg VS/(m^3d), HRT 6 days, temperature (T) 37 °C, WAS content 70 % (v/v), OFMSW content 30% (v/v) and average pH of 5.9.

The maximum value of VFA/CODSOL was found to be 0.9999965, suggested by the optimal value by the model.

The results are depicted in Table 3. These results show the operating parameter to be applied, for the optimal valorization of such feedstock (composed by WAS and OFMSW); in other words, for the maximization of the acidification performances, among others the VFA/CODSOL ratio.

Table 2
The range of input variables for brute-force search

	HRT (D)	T (°C)	WAS/OFMSW (%, V/V)	OLR (KG VS/m^3 D)
MIN	5	15	0	5
MAX	10	70	100	25

Table 3
Optimal values of fermenter operational parameters for maximum vfa/codsol ratio

pH control	Thermal pretreatment	HRT (d)	T (°C)	WAS (%, v/v)	OFMSW (%, v/v)	OLR (kg VS/m^3 d)	pH
0	0	5	55	30	70	21	10.5
0	1	7	23	80	20	16	9
1	0	9	19	90	10	24	8
1	1	6	36	80	20	14	10.5

5. Conclusion

In this study, a regression MLP was developed to simulate the production of VFAs in a continuous fermentation reactor. The MLP model with two hidden layers with ReLU activation functions and one output node, was found to capture most of the important patterns in VFAs production, as it provided an MSE value of 2.7×10^{-3} for the test, which measures the amount of error in the model and evaluates the mean squared difference between the observed and predicted values. Using a simple brute force search, optimal values for HRT, temperature, sludge, food waste, OLR and pH can be predicted to maximize the ratio of VFAs to CODSOL considering four different conditions (without pH control and without thermal treatment, without pH control and with thermal treatment, with pH control and without thermal treatment, and with pH control and with thermal treatment).

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Primena veštačke neuronske mreže u modelovanju i optimizaciji isparljivih kiselina tokom anaerobne digestije biomase

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Fermentacija

I Z V O D

Veštačke neuronske mreže (ANN) zajedno sa Brute Force algoritmima (BF) predstavljaju dve od najčešćih i najjednostavnijih tehnika za modelovanje nelinearnih problema i linearnu pretragu za pronalaženje elementa. Veoma veliki skupovi podataka se zapravo sakupljaju i unose u ANN. Algoritam se pokreće i iterativno vrši milijarde malih prilagođavanja težina i pristrasnosti miliona čvorova. U ovom radu, koristili su se pilot testovi fermentacije u manjem obimu sa mešavinama kanalizacionog mulja i ostataka hrane, kako bi se istražili različiti parametri procesa koji utiču na prinose fermentacije. Pristup mašinskog učenja je korišćen za upravljanje podacima i razvoj modela sposobnog da koreliše performanse procesa na osnovu različitih ulaznih parametara. Kako bi se simulisao rad digestora i procenili izlazi isparljivih masnih kiselina (VFA), razvijen je višeslojni ANN model sa dva skrivena sloja. ANN i BF su korišćeni za simulaciju i optimizaciju VFA iz anaerobne digestije.

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Exploring the Feasibility of Solvent Recirculation in the Extraction Process of (Poly)Phenols from Elderflower (*Sambucus Nigra L.*)

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(Poly)phenols

A B S T R A C T

The traditional maceration technique with a two-step solid-liquid extraction was used in this paper. After the first extraction step, an extract was separated from the exhausted plant material (elderberry flower) and then a plant material was added to the extract. Experimental parameters included different ethanol concentrations (30 %, 60 %, and 90 %), solid-to-solvent ratios (1:15, 1:30, and 1:45 w/v), pH values (3, 7, and 10), and extraction times (15, 30, and 45 minutes), while one-factor-at-a-time (OFAT) was experimental design. The results indicated that the optimal ethanol concentration in the solvent was 60 vol. % for both extraction steps. Increasing the solid-to-solvent ratio from 1:15 w/v to 1:30 w/v resulted in higher (poly)phenol content, with a slight decrease observed at higher ratios. (Poly)phenols content remained consistent in acidic and neutral environments, but decreased at pH 10. While the content of (poly)phenolic compounds increased with longer extraction times, 30 minutes was considered optimal, as further extension did not significantly increase the content. Additionally, it was observed that the content of total (poly)phenols was lower in the second extraction step, suggesting saturation of the solvent after the first extraction..

1. Introduction

Black elderberry (*Sambucus nigra L.*) is a widespread shrub of the Caprifoliaceae family that grows across the majority of Europe, West Asia, North Africa, and the United States (Fazio et al., 2013). It is an evergreen shrub or low tree that can grow up to 10 meters tall and has a rounded, thin canopy. It is often found on the fringes of forests, in thickets and hedges, and along the sides of rivers and streams. It grows in warm, sunny, or semi-shady areas with humid and humus soils (Atkinson and Atkinson, 2002).

The applications of *Sambucus nigra* can be attributed to its characteristic chemical composition, which includes essential oils, free fatty acids, flavonoids, anthocyanins, phenolic acids, carotenoids, vitamins and minerals (Lee and Fin, 2007; Viapana and Wesolowski, 2017). Elderberry flowers have strong antioxidant activity due to their natural polyphenolic components, which include flavanols, phenolic acids, and anthocyanins. (Poly)phenolic compounds are present in the leaves, fruits and flowers.

These compounds are well known as free radical scavengers and can protect the human body from oxidative stress and lipid peroxidation (Sidor and Gramza-Michałowska, 2015).

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Elderberry flowers and fruits, apart from flavonols, contain large amounts of phenolic acids. Fruits contain chlorogenic, crypto-chlorogenic and neochlorogenic acids, as well as trace levels of ellagic acid (0.04 mg/100 g) (Fazio et al., 2013). Elder flowers also contain N-phenylpropenoyl-l-amino acid amides, which strongly stimulate mitochondrial activity and cell proliferation in human keratinocytes and liver cells and inhibit Helicobacter pylori adhesion to the human stomach without causing necrotic toxicity (Hensel et al., 2007; Vasiljević et al., 2023b). The predominant flavonols were quercetin, kaempferol and isorhamnetin. Flavonols derived from elderberry occur as glycosides of rutin and glucose; moreover, acylated quercetins were also present (Christensen et al., 2008). The predominant anthocyanins of *S. nigra* is cyanidin 3-glucoside, depending on the variety and fruition (204.6–481.4 mg cyanidin-3-glucoside equivalents (CGE)/100 g fruits) and cyanidin 3-sambubioside (122.2–269.1 mg CGE/100 g fruits) (Lee and Fin, 2007). The flowers of elderberry contain ten times more flavonols (214.25 mg/100 g) than fruits (20.18 mg/100 g) and several times more than the leaves (17.01 mg/100 g) (Dawidowicz et al., 2006). This paper aimed to investigate how process parameters (extraction time, solid-to-solvent ratio, pH value of solvent, and ethanol content) affected the yield of (poly)phenolic components in an ethanol extract of black elderberry flower. Also, the capacity of the solvent during initial extraction and recirculation will be examined.

2. Materials and methods

2.1. Plant materials and reagents

Dried elderflower blooms, sourced from Zvornik municipality in the eastern part of Bosnia and Herzegovina, were used for extraction. Ethanol served as the solvent for sample extraction, while characterization of the extract employed the following reagents: Folin-Ciocalteu reagent (Carlo Erba, Germany), sodium carbonate (Lach:ner, Czech Republic), gallic acid (Sigma Aldrich, USA), aluminum chloride (Lach:ner, Czech Republic), sodium hydroxide (Lach:ner, Czech Republic), sodium nitrite (Zorka Šabac, Serbia), catechin hydrate (Sigma Aldrich, USA), acetate buffer pH=4.5 (Lach:ner, Czech Republic), and potassium chloride buffer pH=1.0 (Lach:ner, Czech Republic).

2.2. Methods

The determination of total (poly)phenol content relies on oxidation-reduction reactions involving phenol hydroxyl groups and the Folin-Ciocalteu reagent, along with molybdenum and tungsten polymer complex ions. Sodium carbonate is added to the reaction mixture to create a basic environment. Spectrophotometric measurement at 765 nm using gallic acid as the standard was conducted with a Shimadzu 1800 spectrophotometer. Results are expressed in milligrams of gallic acid equivalent per gram of plant material (mg GAE/g) (ISO 14502-1, 2005). Flavonoid content is determined spectrophotometrically with aluminum chloride, forming stable complexes with flavones and flavonols. Spectrophotometric measurement at 510 nm with catechin hydrate as the standard was performed. Results are given in milligrams of catechin hydrate equivalents per gram of plant material (mg CTH/g) (Smolinski-Savi et al., 2017).

Total anthocyanin content, including non-degraded monomers and degradation products, is quantified using the "pH differential" method, involving absorbance measurements at pH=1 and pH=4.5 (Giusti and Wrolstad, 2001). Results are expressed as cyanidin-3-glucoside equivalents (mg Cy3G/g) using a specific formula (Vasiljević et al., 2023a).

$$C_{tot} = (A \cdot M \cdot F \cdot 10^3)/(\varepsilon \cdot l \cdot R)$$

where are:

C_{tot} - total anthocyanins content (mg/g),
A - $(A_{520nm} - A_{700nm})_{pH=1.0}$ - $(A_{520nm} - A_{700nm})_{pH=4.5}$,
M - molar mass (for Cy3G it is 449,2 g/mol),
F - dilution factor ((3+3)/3=2),
10^3- factor for converting grams to milligrams,
ε - molar absorption extinction coefficient (for Cy3G it is 26900 L / (mol·cm)),
l - cuvette thickness (1 cm) and
R - factor for recalculating the value of anthocyanins per gram of drug - mass of drug per volume of solvent (g/L).

A Shimadzu 1800 spectrophotometer was used to determine anthocyanins, the same as it was for total (poly)phenols and flavonoids.

3. Results and discussion

Table 1 presents the results of an investigation into the effects of various parameters on the extraction of total (poly)phenols, flavonoids, and anthocyanins from a selected sample. The variations in experimental conditions include ethanol content, solvent-to-solid ratio, pH value, extraction time, and the number of extraction steps. Each of these parameters significantly influences the number of extracted compounds, which can be observed through changes in their concentrations expressed in mg/g. The results indicate that a 60 % ethanol concentration consistently results in higher yields compared to lower (30 %) and higher (90 %) ethanol levels. Higher solvent-to-solid ratios, such as 1:30 and 1:45, are also more effective, likely due to improved interaction between the solvent and the compounds being extracted. Additionally, neutral (pH 7) and slightly acidic (pH 3) conditions enhance extraction efficiency, suggesting that these pH levels optimize the solubility and stability of the target compounds. Longer extraction times, particularly up to 45 minutes, further increase yields, especially for flavonoids and anthocyanins, as extended durations allow more thorough diffusion of these compounds into the solvent.

The first extraction step is the most productive, yielding the majority of the extractable compounds, while subsequent steps contribute less significantly.

These observations suggest that the initial extraction phase captures most of the available compounds, with diminishing returns in later stages. The impact of each parameter will be discussed in more detail in the following sections.

Table 1
Process parameters and results of (poly)phenolic compound content in the extract

Ethanol content [vol. %]	Solvent-to-solid ratio [w/v]	pH	Extraction time [min]	Extraction step	Content [mg/g]		
					Total (poly)phenols	Flavonoids	Anthocyanins
30	1:30	7	30	1	35.06	27.78	0.048
60					41.42	38.78	0.474
90					25.97	23.82	0.204
30				2	23.35	21.81	0.039
60					39.83	26.49	0.417
90					17.95	18.98	0.206
60	1:15	7	30	1	42.14	30.16	0.374
	1:30				56.73	38.73	0.448
	1:45				54.43	48.02	0.391
	1:15			2	30.10	19.80	0.242
	1:30				45.33	29.90	0.341
	1:45				45.88	31.91	0.361
60	1:30	3	30	1	54.07	37.61	0.364
		7			53.25	35.46	0.380
		10			38.32	26.42	0.362
		3		2	29.42	25.78	0.298
		7			39.20	25.69	0.383
		10			34.93	24.57	0.289
60	1:30	7	15	1	43.05	31.97	0.258
			30		53.86	35.88	0.453
			45		56.50	37.71	0.549
			15	2	31.79	21.83	0.245
			30		37.41	27.74	0.344
			45		43.21	27.99	0.384

3.1. The influence of ethanol content in the solvent on the total (poly)phenol, flavonoid, and anthocyanin content in the extract

Figure 1 depicts the dependency diagram of (poly)phenols, flavonoids, and anthocyanins content on the ethanol content in the solvent, with constant other process parameters (solvent-to-solid ratio = 1:30 w/v, pH = 7, and time of 30 minutes).

The first observation from Figure 1a is that there is an optimal ethanol content in the solvent, at which the highest (poly)phenol content is achieved. Specifically, at a 60 % ethanol concentration, the histogram shows the highest peak. In the first extraction step, the (poly)phenol content increased by 15.35% with an increase in ethanol content from 30% to 60% (rising from 35.06 mg (GAE) / g to 41.42 mg (GAE) / g).

However, further increasing the ethanol content in the solvent from 60 % to 90 % resulted in a decrease in (poly)phenol content by as much as 37.3 % (dropping from 41.42 mg (GAE) / g to 25.97 mg (GAE) / g). Examining the influence of the second extraction step on the total (poly)phenol content, a similar effect as in the first step is noticed, where the (poly)phenol content initially increased and then decreased with an increase in ethanol content in the solvent. Increasing the ethanol content from 30% to 60% led to a remarkable 70.58% increase in (poly)phenol content in the extract (rising from 23.35 mg (GAE) / g to 39.83 mg (GAE) / g). However, increasing the ethanol content from 60% to 90% resulted in a decrease in (poly)phenol content from 39.83 mg (GAE) / g to 17.95 mg (GAE) / g, representing a decrease of 54.94%. Another noticeable aspect is that the extraction yield in the second step is lower than in the first step for all three ethanol content values in the solvent. The reduction in extraction yield is more pronounced when using 30 % and 90 % ethanol compared to 60 % ethanol.

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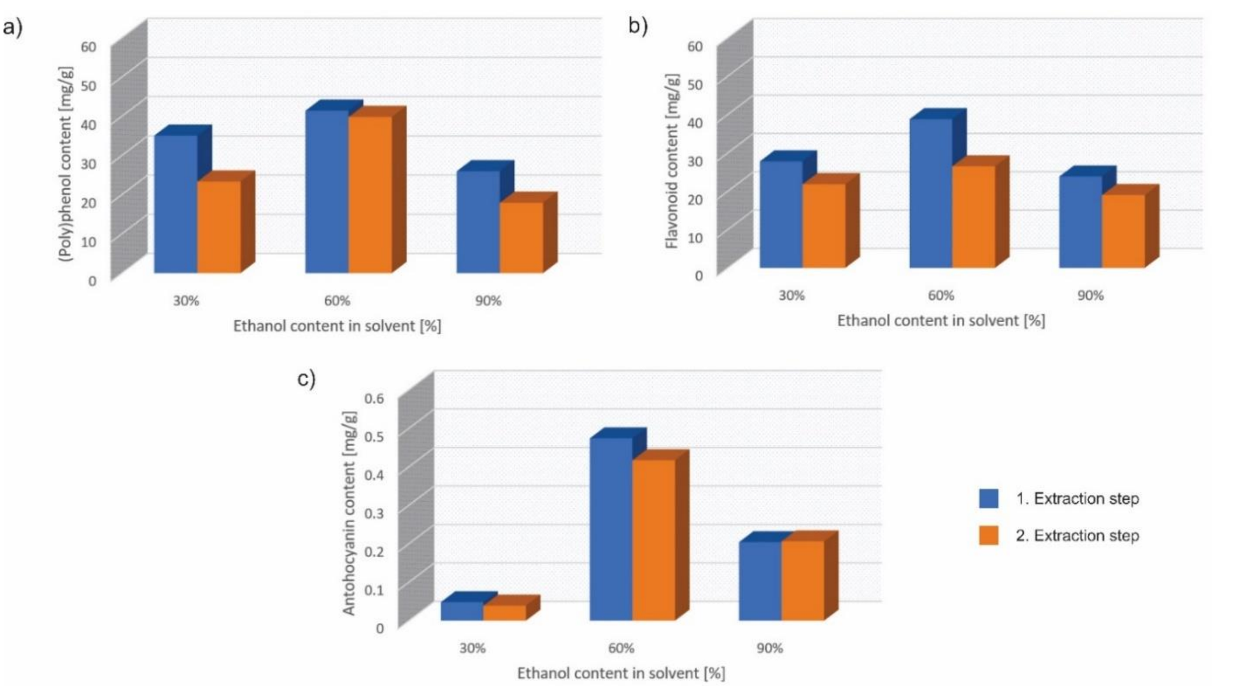

Figure 1. Influence of ethanol content in the solvent on the content of a) (poly)phenols, b) flavonoids, and c) anthocyanins in the extract

Similar to the total (poly)phenol content, there is an optimal ethanol content in the solvent at which the flavonoid content is highest (Figure 1b). In the first extraction step, the flavonoid content increased by 39.60 % with an increase in ethanol content from 30 % to 60 % (rising from 27.78 mg (CTH) / g to 38.78 mg (CTH) / g). However, further increasing the ethanol content in the solvent from 60 % to 90 % resulted in a decrease in flavonoid content by 38.57 % (dropping from 38.78 mg (CTH) / g to 23.82 mg (CTH) / g). Looking at the second extraction step's influence on the total flavonoid content, it is observed that the flavonoid content initially increases from 30 % to 60 % (from 21.81 mg (CTH) / g to 26.49 mg (CTH) / g), and then decreases from 60 % to 90 % (from 26.49 mg (CTH) / g to 18.98 mg (CTH) / g). Comparing the first and second extraction steps, it is noticed that with the use of 30 % ethanol, the flavonoid content in the second extraction step is reduced by 21.49 % compared to the first step (from 27.78 mg (CTH) / g to 21.81 mg (CTH) / g), with 60 % ethanol, this reduction is 31.69 % (from 38.78 mg (CTH) / g to 26.49 mg (CTH) / g), while with 90 % ethanol, this reduction is 20.32 % (from 23.82 mg (CTH) / g to 18.98 mg (CTH) / g).

From Figure 1c, it is evident that the highest anthocyanin content is achieved with the use of 60 % ethanol. In the first extraction step, increasing the ethanol content from 30 % to 60 % resulted in an increase in anthocyanin content from 0.048 mg (Cy3G) / g to 0.474 mg (Cy3G) / g, representing a remarkable 8.875-fold increase. However, further increasing the ethanol content in the solvent from 60 % to 90 % led to a decrease in anthocyanin content (from 0.474 mg (Cy3G) / g to 0.204 mg (Cy3G) / g). Examining the influence of the extraction step, it is observed that in the second extraction step, the anthocyanin content is slightly changed compared to the first step. Once again, there is a significant increase in anthocyanin content with an increase in ethanol content from 30 % to 60 % (from 0.039 mg (Cy3G) / g to 0.417 mg (Cy3G) / g). However, with further increase in ethanol content in the solvent from 60 % to 90 %, the anthocyanin content decreased by 50.60 % (from 0.417 mg (Cy3G) / g to 0.206 mg (Cy3G) / g).

The moderate ethanol content in the solvent (60 vol. %) has a favorable impact on the extraction of total (poly)phenols, flavonoids, and anthocyanins. Solvents with lower ethanol content more easily penetrate plant cells, facilitating the extraction of phenolic compound (Yang et al., 2010). Solvents with higher ethanol concentrations may induce protein denaturation, inhibit the breakdown of phenols from the matrix, and reduce the synthesis of (poly)phenolic compounds (Gunathilake et al., 2019).

3.2. The influence of the solid-to-solvent ratio on the content of total (poly)phenols, flavonoids, and anthocyanins in the extract

The dependency diagram of the content of total (poly)phenols, flavonoids, and anthocyanins in the extract on the solid-to-solvent ratio, with constant other process parameters (ethanol content in the solvent = 60 %, pH = 7, and time of 30 min), is shown in Figure 2.

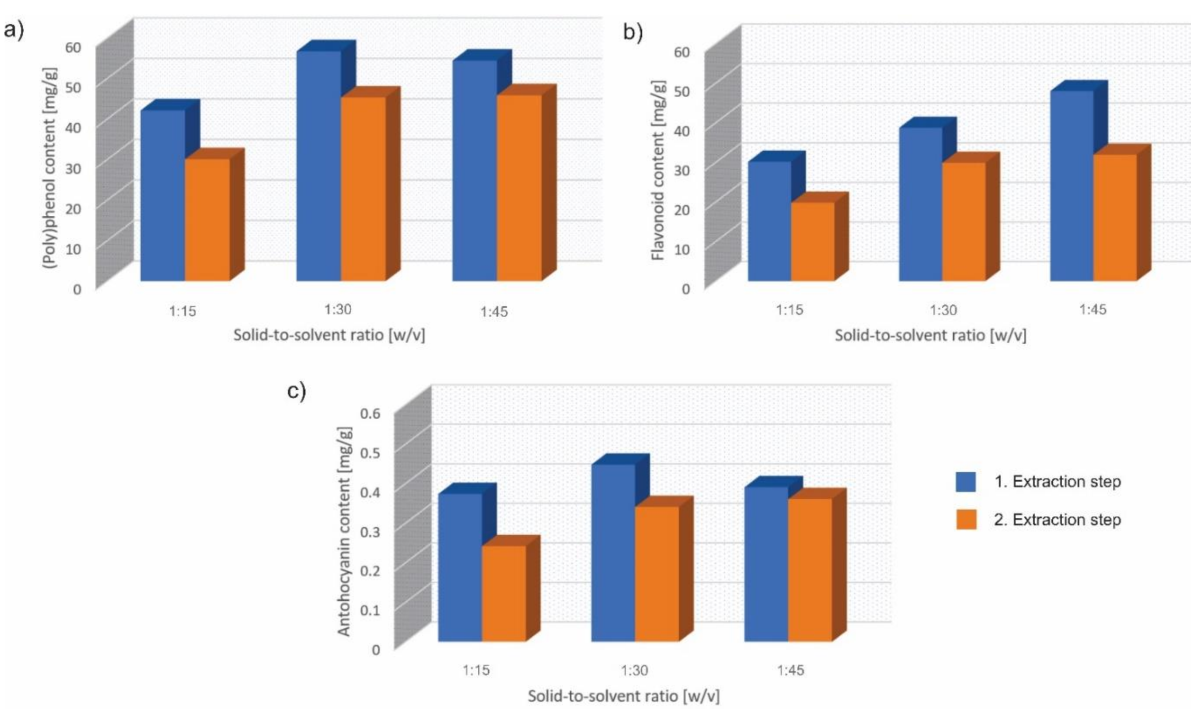

Figure 2. Influence of the solid-to-solvent ratio on the content of a) total (poly)phenols, b) flavonoids, and c) anthocyanins in the extract.

From Figure 2a, it is observed that in the first extraction step, the content of total (poly)phenols in the extract increased by 34.62 % with an increase in the solid-to-solvent ratio from 1:15 w/v to 1:30 w/v (from 42.14 mg (GAE) / g to 56.73 mg (GAE) / g). However, with further increase in this parameter (solid-to-solvent ratio = 1:45 w/v), there is a slight decrease in the total (poly)phenol content in the extract (from 56.73 mg (GAE) / g to 54.43 mg (GAE) / g, representing a decrease of 4.05 %). On the other hand, the influence on the total (poly)phenol content in the extract in the second extraction step is somewhat different. When using the medium (1:30 w/v) and higher ratios (1:45 w/v), similar values of total (poly)phenol content in the extract are observed (45.33 mg (GAE) / g and 45.88 mg (GAE) / g). However, with a solid-to-solvent ratio of 1:15 w/v, the lowest total (poly)phenol content in the extract is observed (30.1 mg (GAE) / g). Similar to the influence of ethanol content in the solvent on the (poly)phenol content, a decrease in (poly)phenol content in the extract is evident in the second extraction step.

From Figure 2b, it is observed that in the first extraction step, the flavonoid content in the extract increases with an increase in the solid-to-solvent ratio. At a solid-to-solvent ratio of 1:15 w/v, the flavonoid content in the extract is 30.16 mg (CTH) / g, at 1:30 w/v it is 38.73 mg (CTH) / g, and at 1:45 w/v it is 48.02 mg (CTH) / g. In the second extraction step, with the use of medium (1:30 w/v) and higher ratios (1:45 w/v), similar values of flavonoid content in the extract are observed (29.9 mg (CTH) / g and 31.91 mg (CTH) / g). However, at a solid-to-solvent ratio of 1:15 w/v, the lowest flavonoid content in the extract is observed (19.8 mg (CTH) / g). Regarding the decrease in flavonoid content in the second step compared to the first step, it is 34.35 % for a solid-to-solvent ratio of 1:15 w/v, 22.80 % for a solid-to-solvent ratio of 1:30 w/v, and 33.55 % for a solid-to-solvent ratio of 1:45 w/v. From Figure 2c, it is observed that in the first extraction step, the anthocyanin content in the extract increased by 19.79 % with an increase in the solid-to-solvent ratio from 1:15 w/v to 1:30 w/v (0.374 mg (Cy3G) / g to 0.448 mg (Cy3G) / g). With further increase in the solid-to-solvent ratio to 1:45 w/v, there is a decrease in the anthocyanin content in the extract by 12.72 % (0.391 mg (Cy3G) / g). In the second extraction step, with the use of medium (1:30 w/v) and higher ratios (1:45 w/v), similar values of anthocyanin content in the extract are observed (0.341 mg (Cy3G) / g and 0.361 mg (Cy3G) / g). However, at a solid-to-solvent ratio of 1:15 w/v, approximately 30% lower anthocyanin content in the extract is observed (0.242 mg (Cy3G) / g). The decrease in anthocyanin content in the second step is least pronounced when using a solid-to-solvent ratio of 1:45 w/v.

When considering the influence of the solid-to-solvent ratio on flavonoid content, it is clear that the highest degree of extraction is achieved at the highest solid-to-solvent ratio. This can be attributed to the larger contact surface area between the sample and the solvent, allowing for more efficient mass transfer of flavonoids from the solid matrix to the liquid phase. A higher ratio can lead to faster mass transfer, resulting in higher yields due to the amount of solvent available for dissolving (poly)phenolic compounds. A higher concentration of solvent in the extraction system often increases extraction efficiency as more solid material is available for interaction with the solvent (Hamdan et al., 2008; Sai-Ut et al., 2023; Vasiljević et al., 2024). On the other hand, the highest content of total (poly)phenols and anthocyanins is extracted at the medium solid-to-solvent ratio. The most likely reason for this phenomenon is that a very high ratio of solid material to liquid may lead to the dissolution of impurities, reducing the solubility of total (poly)phenols and anthocyanins (Liu et al., 2021).

3.3. The influence of pH value on the content of total (poly)phenols, flavonoids, and anthocyanins in the extract

The influence of pH value on the content of total (poly)phenols, flavonoids, and anthocyanins in the extract, with constant other process parameters (ethanol content in the solvent = 60 %, solid-to-solvent ratio = 1:30 w/v, and time of 30 min), is depicted in Figure 3.

From Figure 3a, it can be observed that in the first extraction step, the content of total (poly)phenols in the extract slightly decreased with the increase in pH value from 3 to 7 (from 54.07 mg (GAE) / g to 53.25 mg (GAE) / g). However, the content of total (poly)phenols significantly decreased with further increase in pH value from 7 to 10 (from 53.25 mg (GAE) / g to 38.32 mg (GAE) / g, i.e., by 28.04 %). On the other hand, there is a different effect on the content of total (poly)phenols in the extract in the second extraction step. Increasing the pH value from pH = 3 to pH = 7 resulted in an increase in the content of total (poly)phenols in the extract (29.42 mg (GAE) / g and 39.2 mg (GAE) / g, respectively). However, further increase in pH value to 10 led to a decrease in the content of total (poly)phenols in the extract (34.93 mg (GAE) / g). It is also noticeable that the highest content of total (poly)phenols in the extract (39.2 mg (GAE) / g) was achieved in a neutral environment (pH = 7).

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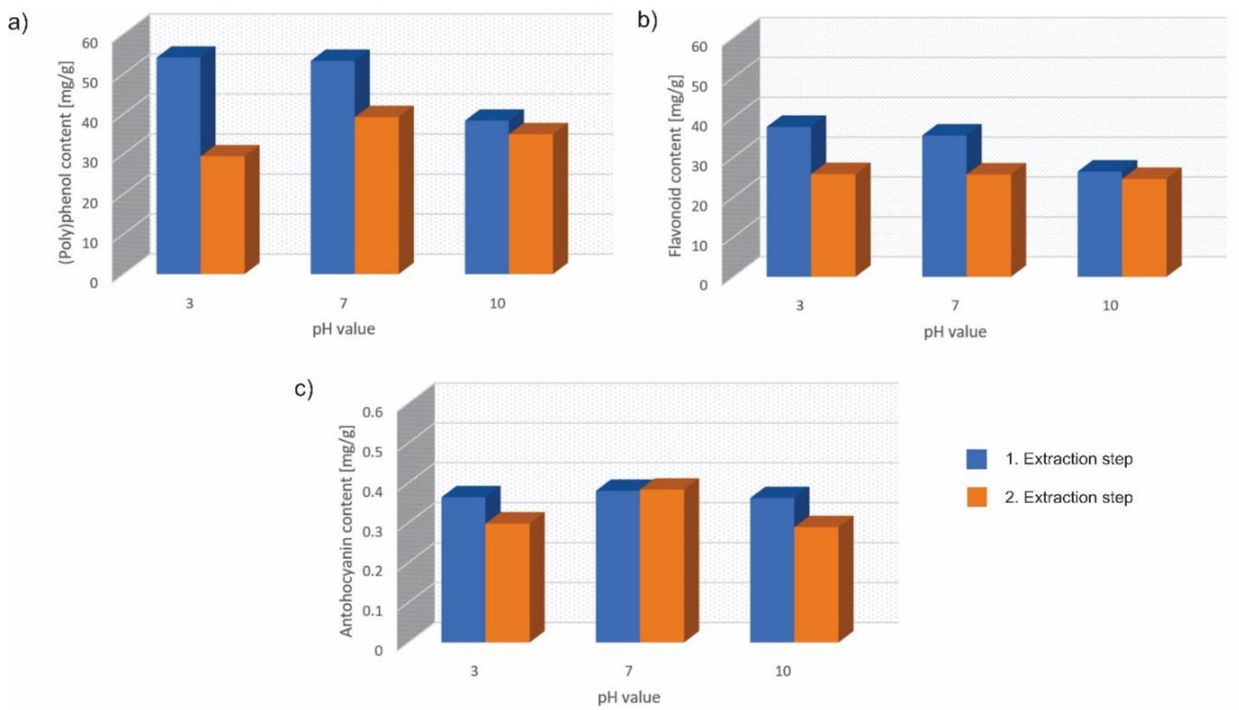

Figure 3. Influence of pH value on the content of a) total (poly)phenols, b) flavonoids, and c) anthocyanins in the extract

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From Figure 3b, it can be observed that in the first extraction step, the content of total flavonoids in the extract was highest at pH = 3 (37.61 mg (CTH) / g). The content of flavonoids in the extract slightly decreased in a neutral pH environment (35.46 mg (CTH) / g), while it significantly decreased in a basic environment (26.42 mg (CTH) / g). On the other hand, in the second extraction step, there were no drastic differences in the content of flavonoids in the extract. Thus, at pH = 3, the content of flavonoids in the extract was 25.78 mg (CTH) / g, at pH = 7 it was 25.69 mg (CTH) / g, and at pH = 10, the content of flavonoids in the extract was 24.57 mg (CTH) / g. It is noticeable here that the highest content of total flavonoids in the extract (25.78 mg (CTH) / g) was in an acidic environment.

From Figure 3c, it can be observed that in the first extraction step, the content of anthocyanins in the extract was highest at pH = 7 (0.38 mg (Cy3G) / g). At pH values of 3 and 10, the content of anthocyanins was slightly lower, at 0.364 mg (Cy3G) / g and 0.362 mg (Cy3G) / g, respectively. In the second extraction step, it is noticeable that at pH = 7, the content of anthocyanins remained almost unchanged (0.383 mg (Cy3G) / g) compared to the first step. On the other hand, when pH = 3 and pH = 10 were used, a decrease in the content of anthocyanins in the extract by 18-20 % was observed (0.298 mg (Cy3G) / g and 0.289 mg (Cy3G) / g, respectively).

The reason for better extraction of (poly)phenols in acidic and neutral environments is that they are slightly acidic compounds, which means they can dissociate into phenolate ions in alkaline solutions. At lower pH values, phenols are in the unionized form, while at higher pH values, they dissociate into phenolate ions.

3.4. The influence of time on the content of total (poly)phenols, flavonoids, and anthocyanins in the extract

Figure 4 illustrates the dependency of the content of total (poly)phenols, flavonoids, and anthocyanins in the extract on time, under constant other process parameters (ethanol content in the solvent = 60 %, pH = 7, and solid-to-solvent ratio = 1:30 w/v).

From Figure 4a, it is observed that the content of total (poly)phenols in the extract is lowest after 15 minutes of extraction (30.16 mg (GAE) / g). With further extraction times of 30 minutes and 45 minutes, there is an increase in the content of total (poly)phenols in the extract (38.73 mg (GAE) / g and 48.02 mg (GAE) / g, respectively). Therefore, by extending the time from 15 minutes to 45 minutes, there is an increase in the content of total (poly)phenols by 59.22 %. The effect in the second

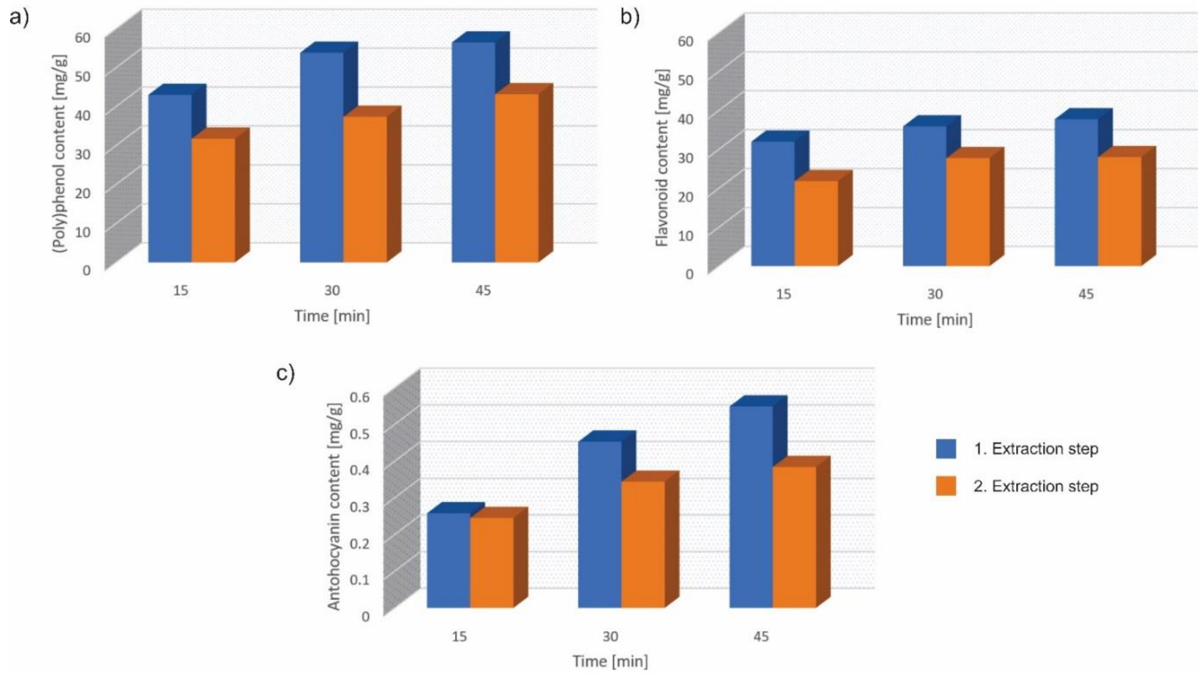

Figure 4. The influence of time on the content of a) total (poly)phenols, b) flavonoids, and c) anthocyanins in the extract

extraction step is similar to the first extraction step. After 15 minutes, the lowest content of total (poly)phenols in the extract is observed (19.8 mg (GAE) / g), while increasing this parameter to 30 minutes increases the content of total (poly)phenols in the extract by 51.01 % (29.9 mg (GAE) / 100 g). With further time extension to 45 minutes, the content of total (poly)phenols slightly increases (31.91 mg (GAE) / g), thus indicating that 30 minutes is the optimal time for the second extraction step.

Looking at the first extraction step from Figure 4b, it is observed that the content of flavonoids in the extract is highest after 15 minutes of extraction (31.97 mg (CTH) / g). With further extension of time to 30 minutes and 45 minutes, there is a slight increase in the content of flavonoids in the extract (35.88 mg (CTH) / g and 37.71 mg (CTH) / g, respectively). Hence, 15 minutes is optimal for flavonoid extraction, as further extension of time does not significantly change its content. In the second extraction step, the lowest content of flavonoids in the extract is observed after 15 minutes (21.83 mg CTH / g). Similar to the first extraction step, further extension of this parameter increases the content of flavonoids in the extract (27.74 mg (CTH) / g after 30 minutes and 27.99 mg (CTH) / g after 45 minutes). Since the flavonoid content does not significantly change after 30 minutes, 30 minutes is considered optimal.

Regarding the first extraction step, Figure 4c shows that the content of anthocyanins in the extract increases with longer extraction times. After 15 minutes of extraction, the anthocyanin content is 0.258 mg (Cy3G) / g, while further extension of time to 30 minutes and 45 minutes results in an increase in the content of anthocyanins in the extract to 0.453 mg (Cy3G) / g and 0.549 mg (Cy3G) / g, respectively. Since increasing the time from 15 minutes to 30 minutes results in a substantial increase in anthocyanin content by 43.04 %, while further extension results in only a 21.19 % increase, 30 minutes is considered optimal for anthocyanin extraction in the first step. In the second extraction step, using a lower parameter value (15 minutes), it is observed that the content of anthocyanins in the extract slightly decreases (0.258 mg (Cy3G) / g in the first step and 0.245 mg (Cy3G) / g in the second step) compared to the first step. At the parameter value of 30 minutes and 45 minutes, there is a significant decrease in the content of anthocyanins in the second step compared to the first step - for 30 minutes, the anthocyanin content is 0.453 mg (Cy3G) / g in the first step and 0.344 mg (Cy3G) / g in the second step, which is a decrease of 24.06 %, while for 45 minutes, the anthocyanin content is 0.549 mg (Cy3G) / g in the first step and 0.384 mg (Cy3G) / g in the second step, which is a decrease of 30.05 %.

4. Conclusion

The moderate ethanol content in the solvent (60 vol. %) has a favorable effect on the extraction of total (poly)phenols, flavonoids, and anthocyanins, as water acts as a swelling agent, while ethanol breaks the bonds between dissolved matter and the matrix. A high concentration of ethanol in the solvent leads to lower yield of (poly)phenolic compounds due to possible protein denaturation, inhibition of phenol breakdown from the matrix, and reduced synthesis of (poly)phenolic compounds. The highest degree of flavonoid extraction occurs at the highest solid-to-solvent ratio due to the greater contact surface area between the sample and the solvent, enabling the more efficient mass transfer of flavonoids from the solid matrix to the liquid phase. A higher ratio can lead to faster mass transfer, resulting in higher yields due to the amount of solvent available for dissolving (poly)phenolic compounds. The highest content of total (poly)phenols and anthocyanins is extracted at a moderate solid-to-solvent ratio because very high ratios lead to impurity dissolution, reducing the solubility of total (poly)phenols and anthocyanins. (Poly)phenol extraction is more efficient in acidic and neutral environments, as they are weakly acidic compounds, which means that they can dissociate into phenolate ions in alkaline solutions. The optimal extraction time for most (poly)phenolic compounds is 15 minutes, as further extension of the time does not significantly increase their content in the extract. Finally, it was found that extraction in the first step is more efficient because the (poly)phenolic compounds diffuse more slowly during solvent recirculation, or the driving force is lower due to solvent saturation.

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Ispitivanje izvodljivosti recirkulacije rastvarača u procesu ekstrakcije (poli)fenola iz cveta zove (*Sambucus nigra L.*)

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INFORMACIJE O RADU

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Ekstrakcija
Flavonoidi
(poli)fenoli

I Z V O D

U ovom radu izvedena je dvostepena ekstrakcija čvrsto – tečno tradicionalnom tehnikom maceracije. Nakon prvog koraka ekstrakcije, ekstrakt je odvojeno istrošenog biljnog materijala (cvet zove), nakon čega je sveži cvet zove dodat ekstraktu. Eksperimentalni parametri uključivali su različite koncentracije etanola (30 %, 60 % i 90 %), odnose čvrsto-tečno (1:15, 1:30 i 1:45 m/v), pH vrednosti (3, 7 i 10) i vremena ekstrakcije (15, 30 i 45 minuta), dok je jedan faktor u vremenu (One-factor-at-a-time (OFAT)) korišćen kao eksperimentalni dizajn. Rezultati su pokazali da je optimalna koncentracija etanola u rastvaraču 60 vol.% za oba koraka ekstrakcije. Povećanje odnosa čvrsto-tečno sa 1:15 m/v na 1:30 m/v rezultuje većim sadržajem (poli)fenola, dok je blagi pad sadržaja (poli)fenola primećen kod većih odnosa čvrsto-tečno. Sadržaj (poli)fenola je približno isti u kiseloj i neutralnoj sredini, dok je u baznoj sredini manji u odnosu na kiselu i neutralnu sredinu. Iako sadržaj (poli)fenolnih jedinjenja raste sa produženjem vremena ekstrakcije, 30 minuta je optimalno vreme budući da se daljim produženjem ne povećava značajno njihov sadržaj. Dodatno, primećeno je da je ukupan sadržaj (poli)fenola bio niži u drugom koraku ekstrakcije, što sugeriše na zasićenje rastvarača nakon prvog ekstrakcionog koraka.

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A Cross Sectional Study on Community Understanding of Battery Waste Impact in Vojvodina

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A B S T R A C T

The issue of waste batteries as a specific type of waste poses a major challenge to the environment, mainly due to improper disposal practices among the local population. The aim of this study is to explore the local population's awareness of the environmental impact of waste batteries, which are often discarded with regular waste instead of being disposed of properly. Although 67 % of respondents express concern about the ecological consequences, 69.63 % of respondents still dispose of used batteries improperly and only 32 % feel sufficiently informed about the environmental risks. The findings highlight the urgent need for targeted education initiatives to raise public awareness of proper disposal methods and the harmful effects of poor waste management on environmental health. The study also highlights the importance of promoting rechargeable batteries and developing accessible collection points to encourage proper disposal. Collaboration with local authorities and alignment with EU regulations are essential for the introduction of sustainable waste management practices.

1. Introduction

Batteries have become an essential part of everyday life in modern society, especially in households where they are used in various devices such as remote controls, toys, clocks, household appliances, and personal care devices. The increasing dependence on portable electronic devices has resulted in the frequent use of various types of batteries. Batteries are practical and make everyday life easier, but their impact on the environment depends on their chemical composition and how they are disposed of after use. For example: zinc-carbon batteries are inexpensive and reliable but have limitations like low energy density and leakage, requiring proper recycling of zinc and manganese due to environmental concerns (Dehghani-Sanij et al., 2019). Silver-oxide batteries are stable but degrade over time, affecting their typical 1.5 V output (Wang et al., 2024). Alkaline batteries are durable and widely used, but 24 % of discarded ones still contain usable energy, causing inefficiency and waste (Sabbaghi and Behdad, 2024). Sealed Ni-Cd batteries, containing toxic cadmium, are banned in the EU but still used in emergencies (Vassura et al., 2009). Ni-Mn batteries offer higher energy density and are more eco-friendly, though recycling is needed to recover rare earth elements (Salehi et al., 2024). Lithium-ion batteries, known for high energy density, are widely used across applications, with lithium ions moving between electrodes during charge and discharge (Reiner et al., 2020). Given that batteries used in everyday applications contain different chemical compositions with hazardous metals, the importance of proper disposal and recycling is paramount to reducing

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their environmental impact. Battery waste management poses a significant environmental challenge due to the potential harm arising from improper disposal like metal leakage, toxicity and climate changes (Melchor-Martínez et al., 2021.).

To reduce the environmental impact of batteries, switching to rechargeable batteries could significantly decrease the demand for single-use batteries. Rechargeable batteries have several advantages over traditional ones. They are cost-effective because they can be reused over 500 times, (Kuchhal and Sharma, 2017) which leads to waste prevention, reducing the volume of waste, and conserving natural resources such as minerals, water, and fossil fuels used in production and transportation (Lankey and McMichael, 2000). In addition, a proper battery storage after end of life ensures a environmental safty (Kuchhal and Sharma, 2017).

In the European Union, the management of batteries and accumulators is regulated by Directive 2006/66/EC. This directive establishes basic standards and objectives for the proper management and recycling of batteries and accumulators, including a ban on placing those containing mercury and cadmium on the market. In Serbia, the transposition of this directive has been achieved through the Waste management law (Official Gazette of RS, 36/2009; 88/2010…35/2023) and the Regulation on the manner and procedure of managing used batteries and accumulators (Official Gazette of RS, 86/2010). There is, however, a gap between legal regulations and the behavior of citizens. Local governments in Serbia currently do not have adequate resources to enforce laws regarding hazardous waste management. As a result, batteries and other hazardous waste often end up in landfills alongside municipal waste. A system for the separate collection of spent batteries and accumulators has not yet been established, nor there are designated locations for their collection, except for a few exceptions. Manufacturers and distributors are responsible for ensuring proper collection and recycling, while public utility companies must organize hazardous waste collection according to local plans. Serbia aims for recycling efficiency of at least 65 % for lead batteries and 75 % for nickel-cadmium batteries (Pokimica et al., 2021). As good practices in battery waste management are sought by both the government and citizens, the results of this study will provide insights into the level of awareness of Vojvodina residents. They will also highlight areas where public education or better management systems are needed. This data will also help identify challenges in promoting sustainable practices in battery disposal and help improve environmental protection efforts.

2. Research Methodology

The survey was implemented in July 2024 through an online questionnaire shared via social media. The aim of the survey was to explore the awareness, opinions, and behavior of residents in Vojvodina when it comes to using and disposing of household batteries, as well as to assess their understanding of the environmental impact of used batteries. The survey consisted of 21 questions, divided into four sections with following crucial indicators:

1. **Basic demographic indicators** - This section helped to create better insights to the respondents' profiles like gender, region of province of Vojvodina, age group, employment status, education level, number of devices operating on battery in their house, and household size. These details are important for analyzing how attitudes and practices might differ among various demographic groups and regions within Vojvodina.
2. **Awareness, concern and practices indicators** - This group of questions focused on respondents' perception of their awareness and concerns of harmful effects of used batteries, and their current disposal habits as well.
3. **Knowledge indicator** - These questions explored their real knowledge on topics such as whether batteries contain hazardous materials (like lead, cadmium, and mercury), whether and how improper disposal affects the environment. Additionally, the survey also investigated their knowledge on recycling systems in Serbia.
4. **Willingness and familiarity indicator** - These questions are designed to reveal willingness to comply with regulations on battery disposal if such laws were enforced, willingness to switch to rechargeable batteries to reduce pollution and questions that indicate if they were informed about collection points.

Most of the answers to the questions were formatted in statements using a Likert scale (from 1 - strongly disagree to 5 - strongly agree), except the question that indicate the knowledge which was formulated in three response options (yes, no, I don't know).

Although each group of questions included several items, we decided to randomly select one question from each group for the analysis:

1. Indicator of **awareness**: What is your opinion on how well-informed you are about the environmental impact of waste batteries?
2. Indicator of **concern**: I am concerned, so I will try to dispose of batteries properly in the future, in designated places.
3. Indicator of **practice**: I throw batteries in the waste bin with other household waste/I dispose of batteries in designated collection places.
4. Indicator of **knowledge**: What is your opinion on

whether cadmium, lead, and mercury are classified as hazardous materials?

5. Indicator of **familiarity**: I am familiar with the locations (in my place of residence or the nearest city) where waste batteries are collected.
6. Indicator of **willingness**: Since rechargeable batteries significantly reduce potential environmental pollution caused by improper disposal, would you be willing to change your lifestyle habits and invest more money in purchasing rechargeable batteries and chargers to help reduce the generation of this type of waste?

To reveal the main correlations between indicators (awareness, concern, practices, knowledge, familiarity and willingness), an analysis was conducted through various respondent variables (age, education and number of devices that operate on battery in household). For this comparative analysis only affirmed answers of selected questions were analyzed.

3. Results and discussion

3.1. Respondents' profile

A total of 110 respondents participated in the survey, representing all three regions of the province of Vojvodina: Srem, Banat, and Bačka. The majority of respondents were female (72.7 %). Regarding the regions in Vojvodina where respondents live, 76.4 % reside in Banat, 18.2 % in Bačka, and 5.5 % in Srem. The respondents' employment status, education, age, and the distribution of battery-powered devices in households are presented in Table 1. The majority of participants (71.8 %) were employed, while only 14.5 % were students. A total of 10 % of respondents declared themselves unemployed, and 3.6 % were retirees. The majority of participants in the survey (52.7 %) completed secondary education, followed by 29.1 % who had higher education. Answers also revealed that batteries of various sizes and types are used in households to power different devices. Among the respondents, 36.4 % have more than seven devices that operate on batteries, while 33.6 % have five to six devices. Slightly fewer respondents, 26.4 %, use batteries to operate three to four devices, and 3.6 % use them for one to two devices.

Effective management of battery waste is a pressing environmental concern. A comprehensive study conducted in Sydney (Islam et al. 2022) involved a sample of 400 respondents, representing a population of approximately 5.18 million. In contrast, the research conducted in Vojvodina had a sample of 110 respondents, corresponding to a smaller population of around 1.8 million. Although the sample size in Vojvodina is smaller, it can still yield relevant results as it reflects the specific characteristics of the local community. The sampling approach in Vojvodina was adapted to the size and context of the targeted communities, allowing for meaningful insights despite the differences in sample size.

Table 1.
Employment status, education, household size, and age distribution of respondents

Category	Subcategory	Percentage (%)
Age Group	41 to 50 years	30.0
	21 to 30 years	29.1
	31 to 40 years	21.8
	51 to 60 years	11.8
	Under 20 years	4.5
	61 to 70 years	1.8
	Over 70 years	0.9
Employment Status	Employed	71.8
	Students	14.5
	Unemployed	10
	Retired person	3.6
Educational Attainment	Secondary Education	52.7
	Higher Education	29.1
	Master's Degree	5.5
	Primary Education	2.7
	Doctoral Degree	1.8
Number of devices on battery in households	1-2	4
	3-4	29
	5-6	37
	>7	40

3.2. Analysis of indicators and their correlation to the variables

Data obtained within this research are analyzed in order to reveal main challenges in battery waste management and public participation. Hence, correlation between indicators for awareness, concern, practice, knowledge, familiarity and willingness was analyzed through different variables of respondents: age, education and number of devices of battery in household.

For **Indicator of awareness**, we selected question "What is your opinion on how well-informed you are about the environmental impact of waste batteries?". According to respondents answers only 32 % affirmatively responded that they believe that they are aware about environmental impact of battery waste (Figure 1). Compared to studies in China, where over 90 % of 1,874 respondents are aware of the health and environmental risks of spent batteries, this percentage is significantly low (Sun et al., 2015). In order to indicate profile of that group of respondents we investigated their age, education and the number of

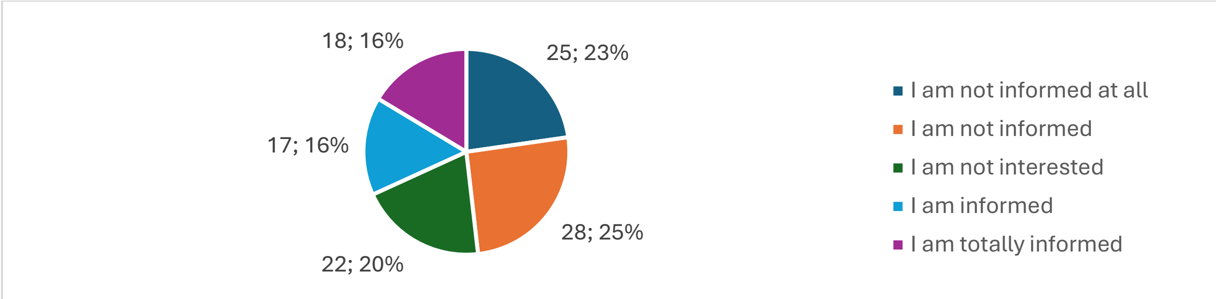


Figure 1. Structure of the answers on question What is your opinion on how well-informed you are about the environmental impact of waste batteries?

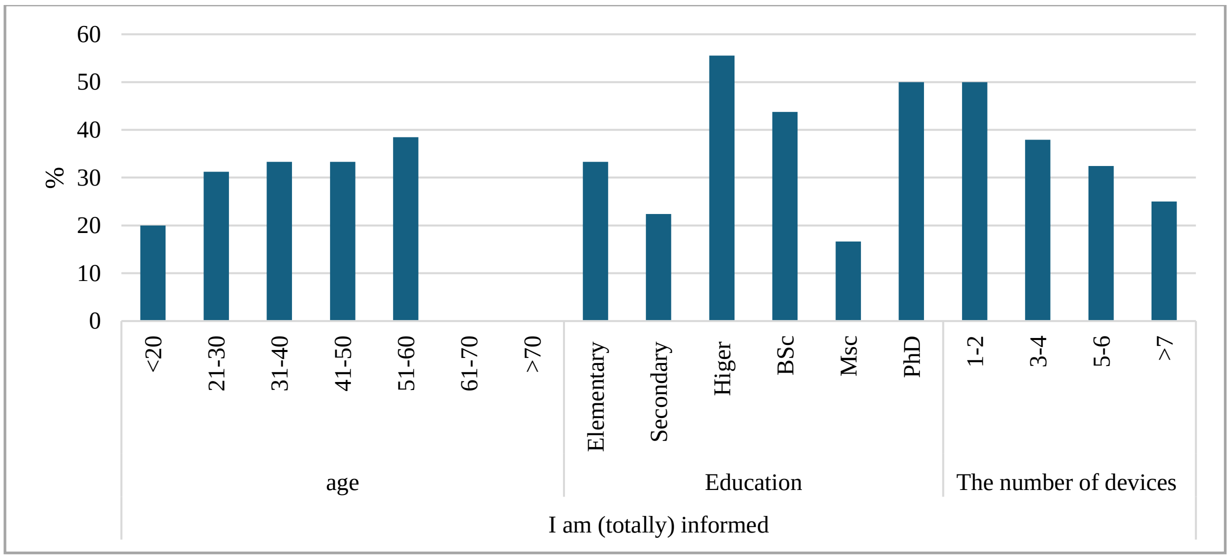


Figure 2. Incubator awareness in correlation to the participants variables

devices powered by batteries of various types and sizes in household. Results revealed that younger people (less than 20-year-old) are the group that is the least aware of battery waste impacts.

Concerning the respondent's education, citizens with higher education and the group of people that have only 1-2 device that uses battery in their houses think that they are totally aware of the influence battery waste has on environment (Figure 2). This suggests the need for stronger educational campaigns to raise awareness on this topic, especially among younger respondents. **For indicator of concern**, we selected question: "I am concerned, so I will try to dispose of batteries properly in the future, in designated places. Results showed that majority of respondents (67 %), confirmed that they are concerned about environmental damage that old battery cause (Figure 3).

In addition, we analyzed the group of respondents who were very concerned based on the variables mentioned above. According to the analysis, participants in the 61-70 age group are the most concerned group. This group also includes the more educated participants and those who own 3-4 devices that run on batteries.

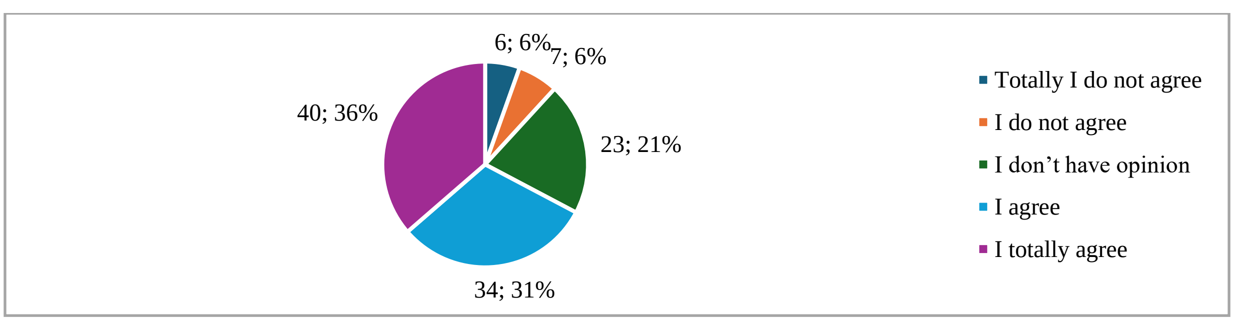


Figure 3. Structure of the answers on question

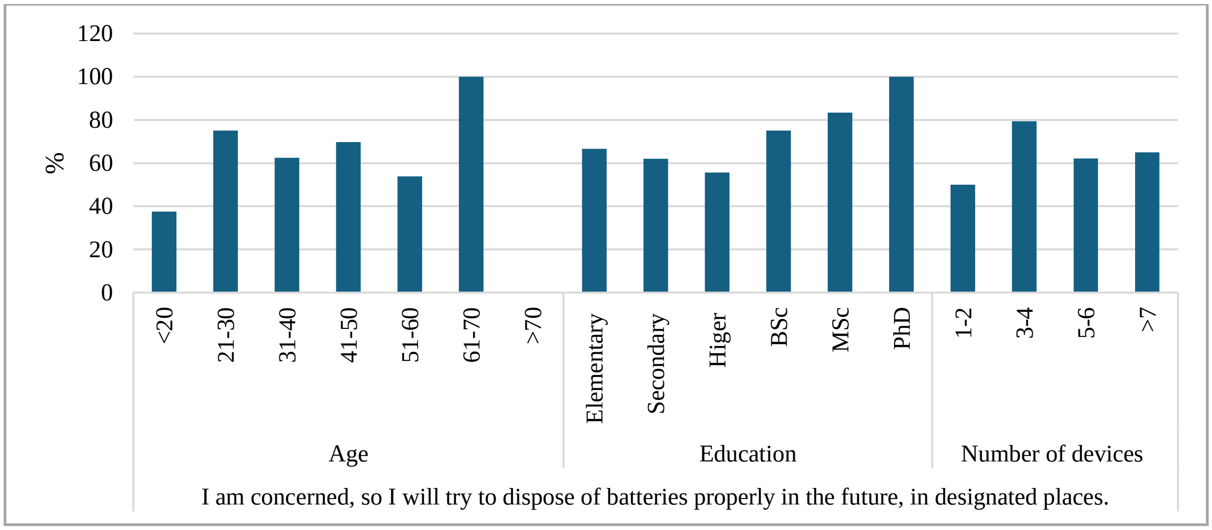


Figure 4. Indicator concern in correlation to the participants variables

Answers for **indicator of practice**: "I throw batteries in the waste bin with other household waste/I dispose of batteries in designated collection places" showed that, majority of respondents throw the batteries the trash with household waste (69.63 %). Affirmatively we choose to analyze the profile of respondents who stated that dispose batteries at special points designated for used batteries (39.35 %) (Figure 5). A comparable study was conducted among residents of Dezhou and Zibo City in Shandong Province from May to August 2014, focusing on the methods of battery disposal. The study involved 1,975 participants, revealing concerning trends in waste management. It was observed that the collection practices for waste batteries from households were inadequate, with respondents mostly disposing of batteries alongside municipal waste (Sun et al., 2015). In related research conducted in Sydney (Islam et al. 2022), 27 % of respondents dispose of waste batteries in bins along with municipal waste. Moreover, a study in Malaysia (Mathew et al. 2023), revealed that a significant proportion of respondents have never recycled spent lithium-ion batteries, often choosing to store them at home or throw them away instead of using recycling bins.

However, the lack of proper disposal practices suggests that it is essential not only to inform people about the dangers but also to actively engage them in recycling processes and proper disposal methods.

To better understand the profile of this group of respondents we provided deeper insights into their habits related to battery disposal (Figure. 6).

Comparative analysis showed that all respondents with a PhD education dispose of batteries at designated collection places. Additionally, those who have high number of battery-operated devices (5-6) in their households also showed good practice in battery disposal.

For **indicator of knowledge**, we selected question: "What is your opinion on whether cadmium, lead, and mercury are classified as hazardous materials?" Based on the research results, it can be concluded that 94 % of respondents believe they are aware that cadmium, lead, and mercury are classified as hazardous materials (Figure 7). However, their knowledge is questionable because there is a clear gap between what they say and their actual behavior when it comes to disposing of batteries in the trash with other waste. Based on the research conducted in Russia (Tarasova et al., 2012), a similar situation emerged where respondents who recognized the harmful environmental impact of spent batteries still opted to dispose of them in the trash.

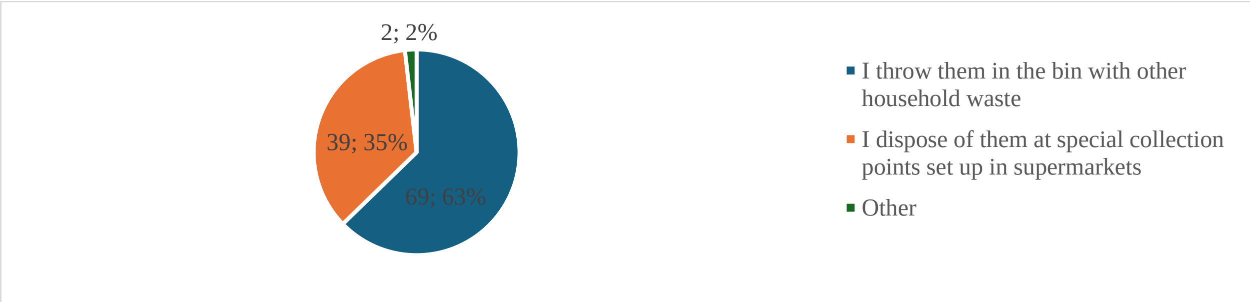


Figure 5. Structure of the Answers to the Question: "I throw batteries in the waste bin with other household waste / I dispose of batteries in designated collection places"

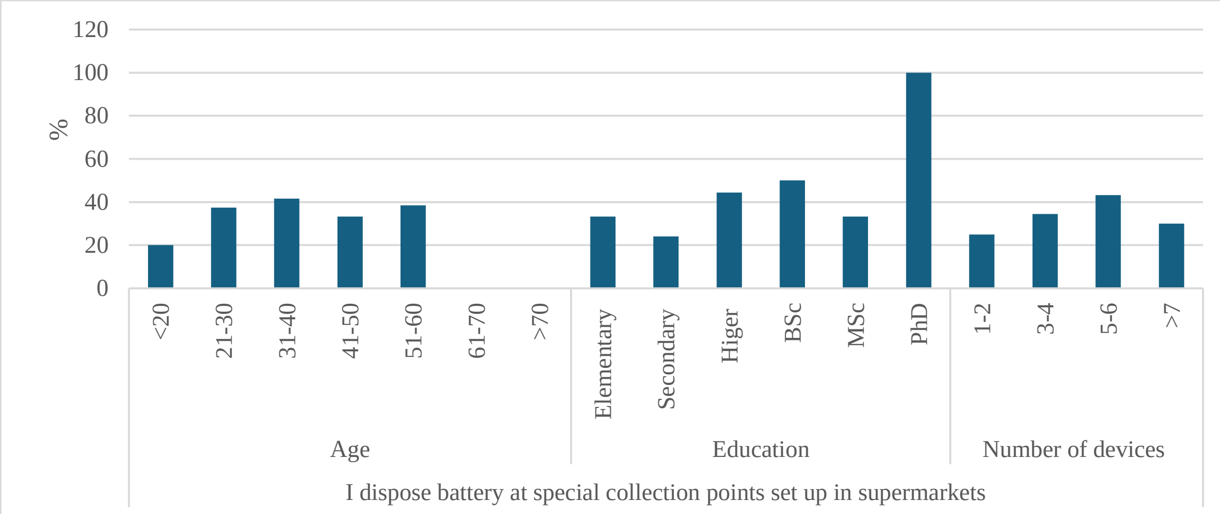


Figure 6. Indicator practice in correlation with the participants' variables

Based on the data presented in Figure 8, we can conclude that none of the examined groups across the three variables stand out in the category of the knowledge indicator. However, the question was formulated in such a way that respondents, even though they may not have been fully aware of the impact, hinted at the correct answer. It seems that all participants demonstrated same level of knowledge.

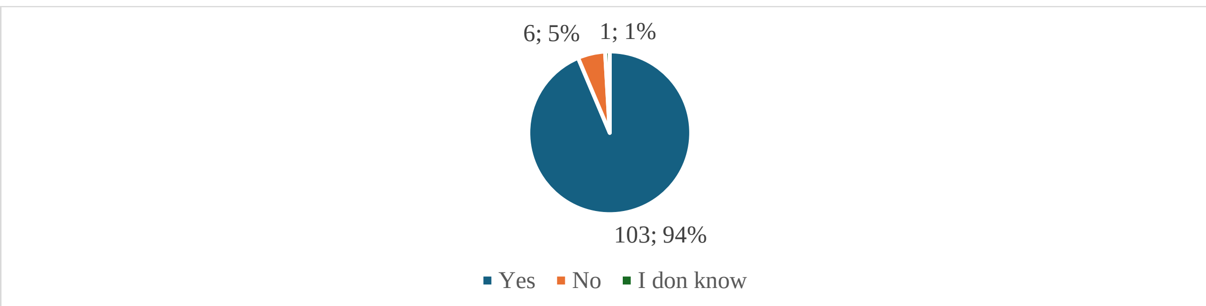
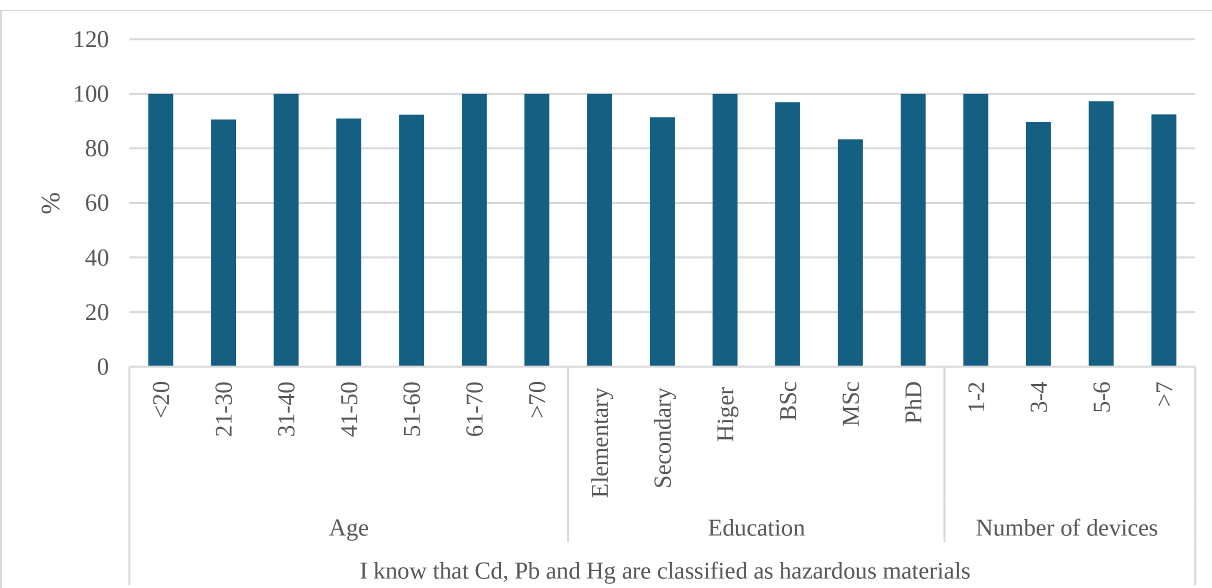


Figure 7. Structure of the answers on question "Are the cadmium, lead, and mercury classified as hazardous materials?"



Graph 8. Indicator knowledge in correlation with the participants' variables

For **Indicator of familiarity**, we selected question: "I am familiar with the locations (in my place of residence or the nearest city) where waste batteries are collected." As depicted in Graph 9.42 % of respondents reported familiarity with these designated locations.

Conversely, 51 % of participants indicated that they are unaware of where to dispose of waste batteries properly.

This lack of familiarity and insufficient infrastructure not only hinders effective recycling practices but also underscores the urgent need for a more robust waste battery management system in Serbia.

For analysis correlation of indicator with the participants' variables, group of respondents that stated that they are familiar with the battery disposal locations were selected.

The data indicates that respondents aged under 20 and those between 21 and 30 years are significantly less familiar with battery disposal sites. In contrast, respondents with a PhD education emerge as the most familiar group in this category.

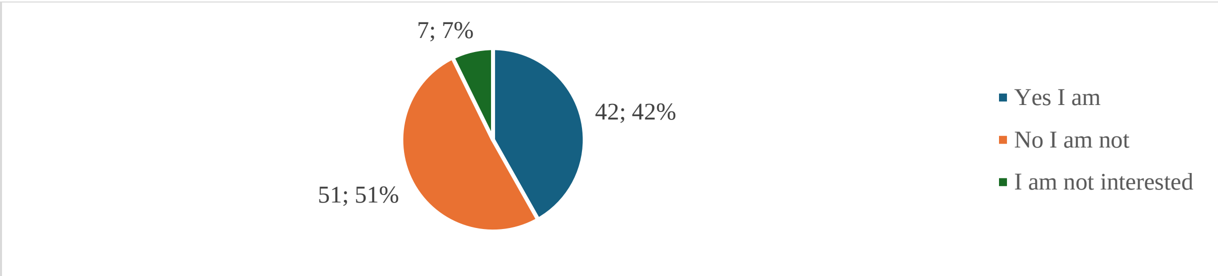


Figure 9. Structure of the answers on question: I am familiar with the locations (in my place of residence or the nearest city) where waste batteries are collected

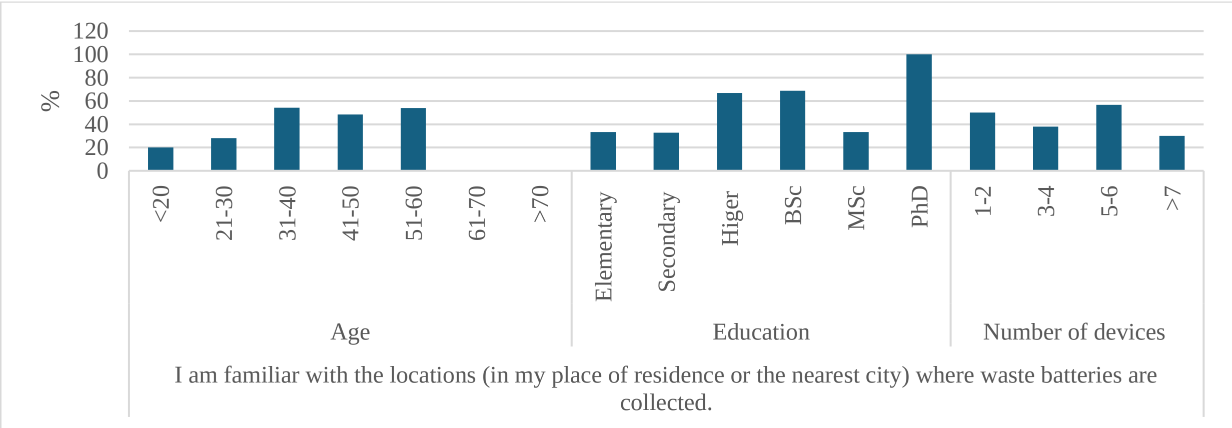


Figure 10. Indicator familiarity in correlation with the participants variables

For **Indicator of willingness** following question was selected: "Since rechargeable batteries significantly reduce potential environmental pollution caused by improper disposal, would you be willing to change your lifestyle habits and invest more money in purchasing rechargeable batteries and chargers to help reduce the generation of this type of waste?" The results indicate that an impressive 78 % of respondents express a willingness to modify their habits and invest in rechargeable options to help reduce the generation of this type of waste (Figure 11).

This result provides a foundation for developing strategies that could further encourage the transition to more sustainable options while simultaneously reducing the negative impact of battery waste on the environment.

The following graph (Figure 12) provides a detailed profile of respondents who expressed full willingness to change their lifestyle habits.

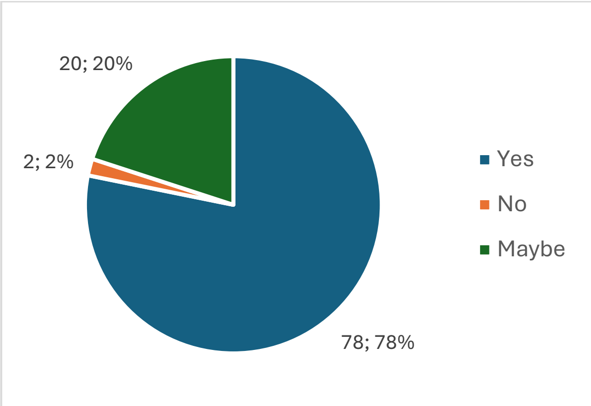


Figure 11. Structure of the answers on question: Since rechargeable batteries significantly reduce potential environmental pollution caused by improper disposal, would you be willing to change your lifestyle habits and invest more money in purchasing rechargeable batteries and chargers to help reduce the generation of this type of waste?

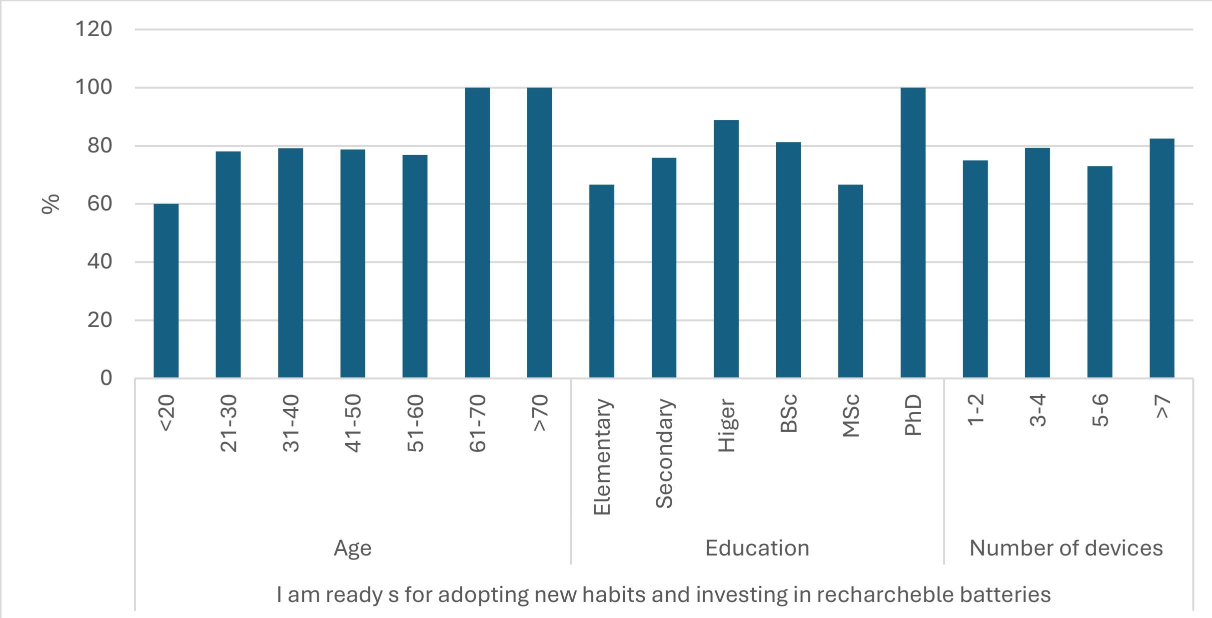


Figure 12. Indicator willingness in correlation with the participants variables

Based on the research findings, it can be concluded that older respondents, particularly those in the age groups of 61-70 and over 70 years, are the most willing to change their lifestyles regarding the purchase of rechargeable batteries.

4. Conclusion

The research on the issue of battery waste highlights the serious ecological challenges posed by the improper disposal of this specific type of waste. The results indicate that only 32 % of respondents feel adequately informed about the impact of battery waste on the environment. While the majority, 67 % of respondents, express concern about the ecological consequences of old waste, as many as 69.63 % still dispose of batteries in regular waste instead of designated disposal sites. These data clearly demonstrate the need for several actions.

First, educational campaigns are necessary to raise awareness about the environmental risks of improper battery disposal and inform citizens about best practices. Infrastructure development is also required, especially to provide accessible and well-marked battery collection points in the community to encourage proper disposal. Another important action is the promotion of rechargeable batteries, emphasizing their longevity and lower environmental impact. Finally, collaboration with local authorities is essential to ensure the effective implementation of waste management regulations.

In line with European Union regulations and local laws, it is essential to improve the infrastructure for the collection and recycling of used batteries to ensure the proper management of this hazardous waste. By implementing educational initiatives and building an efficient collection system, it is possible to significantly reduce the impact of battery waste on the environment.

This approach not only aligns with sustainable waste management practices but also contributes to the circular economy by maximizing resource recovery and minimizing waste.

This study provides valuable insights into the level of awareness among citizens of Vojvodina and identifies key areas for improvement in public education and waste management systems.

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Studija preseka o shvatanju uticaja otpada od baterija u zajednici u Vojvodini

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Svest Zajednice
Upravljanje Otpadom

I Z V O D

Problem istrošenih baterija kao specifične vrste otpada predstavlja veliki izazov za životnu sredinu, pre svega zbog nepravilnih praksi odlaganja među lokalnim stanovništvom. Cilj ove studije je da istraži svest lokalnog stanovništva o ekološkom uticaju istrošenih baterija, koje se često odbacuju zajedno sa komunalnim otpadom umesto da se pravilno odlažu. Iako 67 % ispitanika izražava zabrinutost zbog ekoloških posledica, 69,63 % njih i dalje nepravilno odlaže iskorišćene baterije, a samo 32 % se oseća dovoljno informisano o ekološkim rizicima. Nalazi ukazuju na hitnu potrebu za ciljanom edukacijom radi podizanja svesti javnosti o pravilnim metodama odlaganja i štetnim efektima lošeg upravljanja otpadom na životnu sredinu. Studija takođe naglašava značaj promovisanja punjivih baterija i razvoja dostupnih punktova za prikupljanje, kako bi se podstaklo pravilno odlaganje. Saradnja sa lokalnim vlastima i usklađivanje sa regulativama EU su ključni za uvođenje održivih praksi upravljanja otpadom.

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Analysis of the Problems Related to Traffic and Road Infrastructure in the Area of the Timisoara Student Complex

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ABSTRACT

A common problem in many cities is the continual growth in the number of personal vehicles, which creates numerous challenges and impacts on the environment, the local economy and, most importantly, on the communities and individuals who live and work in these areas. This increase in traffic brings to the forefront issues such as road congestion, air pollution, longer journey times and damage to existing road infrastructure. The aim of this paper is to investigate and analyze the impact of the increase in the number of personal vehicles on traffic and road infrastructure in the student complex of Timisoara. By studying this problem, possible solutions and measures were identified to effectively address these challenges and improve the quality of life of the residents in the area.

1. Introduction

In modern society, road traffic and the corresponding infrastructure are two fundamental issues that influence the quality of life of people living in an urban area.

Urban traffic is a key area of study in the planning and management of cities, especially developing ones, involving the flow of vehicles, people and goods moving on transportation arteries in urban areas.

Road infrastructure is a major issue for local government administrators and, like all other assets in a region, requires effective management. Such management should include not only the planning, implementation and monitoring of all activities related to the maintenance and development of the road network and its engineering structures, but also the creation of conditions conducive to the interactivity and efficiency of road infrastructure, while minimizing associated costs. (Świtała, 2023)

The rapid development of private motorization over the last two decades has contributed to numerous negative phenomena, affecting road transport safety and air quality in congested areas. The impact of transport on the environment is often adverse and unavoidable. (Skrúcany et al., 2017) The negative effects of traffic congestion are most evident in large cities, where traffic density is high and vehicle speeds are characteristically low and often variable, involving frequent accelerations and decelerations. (Raslavicius et al., 2015)

In recent years, the development of transport infrastructure has advanced considerably, but traffic problems continue to worsen due to the growing urban population that requires the use of these means of transport. (Medina-Salgado et al., 2022) This phenomenon has led to increasing problems related to congestion control, with a direct impact on citizens: air pollution, excessive fuel consumption, traffic violations,

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noise pollution, accidents and loss of time. (González-González et al., 2020)

The urban traffic problems that can arise from less than intelligent urban planning lead to several factors that affect the smooth functioning of cities, which will be briefly discussed below:

- Delays and loss of productivity: Traffic congestion leads to significant delays in the movement of people and goods, resulting in lost time and reduced productivity. (Button and Vega, 2021) Time spent in traffic means lost time for work, education, leisure and family. Congestion also has a negative impact on traffic reliability and makes it difficult to plan journeys and deliver goods. (He and Mak, 2024)

- Increased greenhouse gas emissions: Vehicles stuck in traffic consume more fuel for the same distance traveled in normal flowing traffic. This delay increases emissions of CO_2 and other greenhouse gasses, contributing to climate change and global warming. In addition, vehicles that idle for too long or travel at low speeds emit larger amounts of pollutants. (Wang and Hao, 2022)

- Impact on public health: High levels of traffic contribute to the deterioration of air quality in urban areas through the emission of fine particulate matter, nitrogen oxides, carbon monoxide, hydrocarbons and other harmful substances. (Li and Zao, 2020) Long-term exposure to these pollutants has been linked to a range of health problems, including respiratory and cardiovascular diseases. (Kim and Lee, 2023)

In this article, we examine the impact of the increase in the number of vehicles on traffic and road infrastructure in the student complex of Timisoara. The idea of this article stems from the observation that in recent years, the number of vehicles circulating in and around the student complex has increased significantly with the increase in the number of students who choose the city of Timisoara in the context of their academic development, but also their convenience to use, to a large extent, their personal vehicles as a means of transportation, generating various challenges and impacts on the daily life of the local community and the quality of the urban environment.

Timisoara's student complex is no exception to these problems, having witnessed a significant increase in the number of personal vehicles in recent years. In this densely populated area, characterized by the presence of student residences and numerous student facilities, efficient traffic management and the provision of adequate road infrastructure are crucial for the smooth functioning of the local community and the quality of life of students and residents.

2. Materials and Methods

A descriptive research approach was chosen for this work. The descriptive approach allows for a detailed examination of the characteristics and behavior of the studied phenomenon, identifying patterns and providing a clear picture of the current traffic and road infrastructure situation in the student complex.

Data collection was based exclusively on primary data, as this data is up-to-date and contributes to a greater extent to solving the traffic problem. One method in particular was used to collect the primary data: the questionnaire. To collect the data, an online questionnaire was created and distributed to students, university staff and anyone living in or near the student complex using Google Forms. The questionnaire assessed frequency of personal vehicles use, mode preferences and perceptions of traffic conditions and infrastructure. The questionnaire was distributed online via the Google Forms platform, and could be completed from 25 April 2024. A total of 92 valid responses were collected, ensuring an adequate representation of the sample.

The questionnaire was divided into four main sections, each of which aimed to explore a specific aspect of the impact of vehicles on traffic and road infrastructure:

- Demographic information: Questions on respondents' age, gender and status as a student, resident or employee.

- Use of personal vehicles: Questions about ownership and frequency of use of personal vehicles in and around the student complex.

- Perception of traffic and parking: Questions about perceptions of traffic congestion and parking availability.

- Participants' views on solving traffic problems: open-ended questions in which questionnaire respondents express their views on how traffic problems could be solved.

Figures 1 and 2 show the Student Dormitory Complex. The figures show the main streets within the complex. These streets were selected for traffic observation because they have a high volume of traffic, especially during peak hours. Figure 3 shows the occupancy of the parking spaces in the area of student complex, which is much higher than that of the specially designated parking spaces.

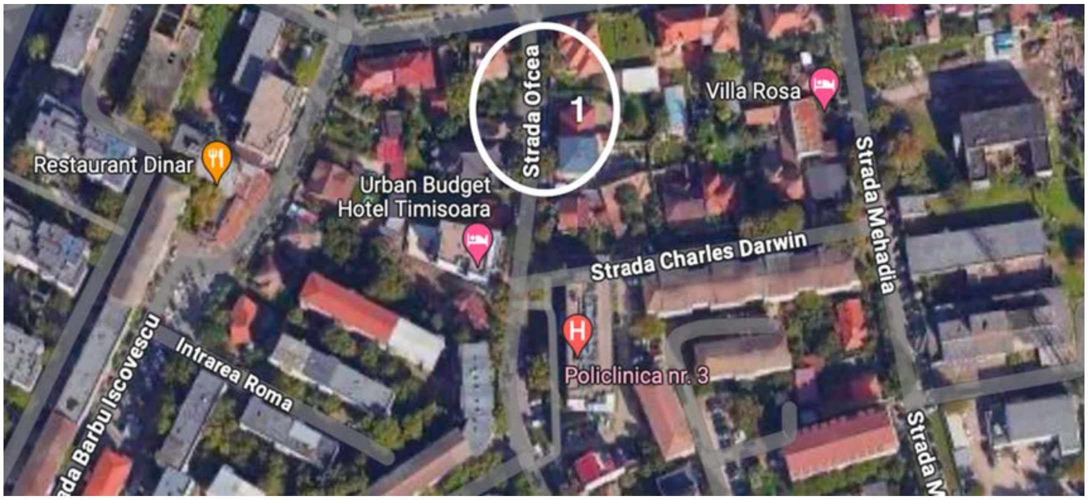

Figure 1. Data collection points on Ofcea Street (source Google Maps)

Figure 2. Data collection points on Vidu, Ripensia and Eroilor de la Tisa streets (source Google Maps)

Figure 3. Overcrowded parking lots in the student dormitory complex

3. Results and discussions

The analysis of the data from the questionnaire revealed the following, as shown in the figures below:

1. There are two peak traffic times: 7:30 ÷ 9:30 and 16:00 ÷ 18:00,
2. Traffic in the area of student complex has become very congested in recent years, leading to long waiting times,
3. More than 80 % of respondents believe that other means of transport should be used in this area and that awareness campaigns should be organized among the residents of this area and the citizens of Timisoara.

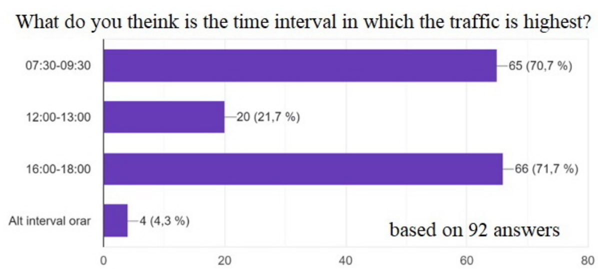

Figure 4. Time of day with the highest traffic

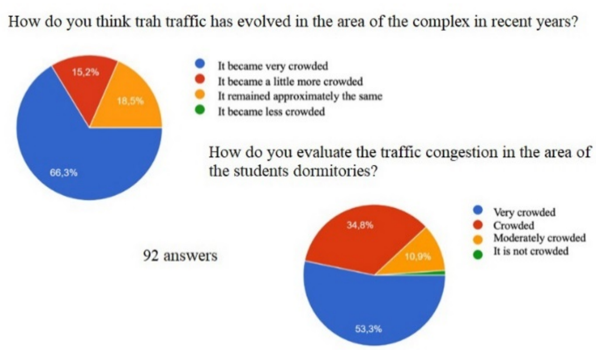

Figure 5. Traffic evolution in the student complex area

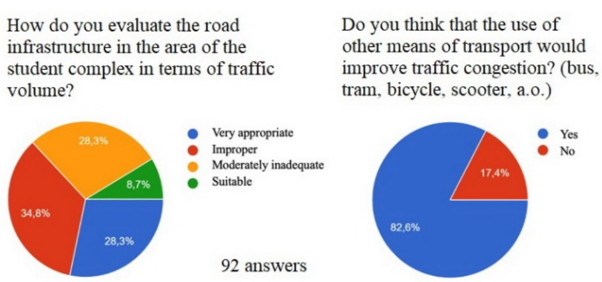

Figure 6. Road infrastructure assessment and improvement

Figure 6 provides general overview of the infrastructure within the student complex in relation to the existing traffic conditions. This aspect is particularly important for the permanent resident population. The questionnaire also included questions about suggested alternative modes of transportation for students to improve traffic congestion in the area.

According to the traffic measurements carried out in the studied area and the answers given by the target persons in the questionnaire related to the work, a significant increase in traffic volume was observed, leading to congestion on the main access roads to the student complex of Timisoara.

4. Conclusions

The student complex traffic study revealed an increased number of vehicles causing significant congestion during peak study times, which impacted traffic flow and increased travel time. Congestion also contributes to increased stress for drivers and pedestrians while reducing road safety by increasing the risk of accidents.
The road infrastructure was affected depending on the volume of traffic on the streets where we conducted the study. The streets have potholes and bumps in the asphalt, making traffic difficult and increasing the risk of accidents and premature damage to vehicles, while affecting the comfort and safety of drivers and pedestrians.
Responses to the questionnaire for the study revealed that promoting public transport and alternative modes of transportation can reduce congestion and improve urban mobility.

Acknowledgement

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Analiza problema vezanih za saobraćaj i putnu infrastrukturu u području studentskog kompleksa u Temišvaru

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Saobraćaj
Putna infrastruktura
Praćenje saobraćaja
Saobraćajna gužva

I Z V O D

Zajednički problem mnogih gradova jeste kontinuirani rast broja ličnih vozila, što stvara brojne izazove i ima uticaj na životnu sredinu, lokalnu ekonomiju i, što je najvažnije, na zajednice i pojedince koji žive i rade u tim oblastima. Ovaj porast saobraćaja dovodi u prvi plan pitanja kao što su saobraćajne gužve, zagađenje vazduha, duže vreme putovanja i oštećenja postojeće putne infrastrukture. Cilj ovog rada je da istraži i analizira uticaj povećanja broja ličnih vozila na saobraćaj i putnu infrastrukturu u studentskom kompleksu u Temišvaru. Kroz proučavanje ovog problema, identifikovana su moguća rešenja i mere za efikasno rešavanje ovih izazova i poboljšanje kvaliteta života stanovnika ovog područja.

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Assessment of Sewerage System and Impacts of Wastewater on the Environment and Reusing in Erbil City

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ABSTRACT

This study provides a comprehensive assessment of the sewage system in the city of Erbil, Iraq, focusing on the wastewater's quality, quantity, and the environmental impact of untreated wastewater disposal. The city does not have a centralized wastewater treatment plant, although a design has already been approved. The study evaluates the current system by comparing existing data with previous research and highlighting the impact of lifestyle on wastewater characteristics in the region. The study highlights the dangers of reusing untreated wastewater for irrigation, which poses significant health and environmental risks, including groundwater contamination. Data was collected through site visits to various locations in the city of Erbil. The research discussed the current and potential impacts of wastewater on watercourses. It was found that the majority of wastewater in Erbil is discharged untreated into the environment, causing significant pollution problems. The total amount of produced wastewater and irrigated area is 257,184 m^3/day and 5,143,680 m^2/day respectively. In addition, the study concluded with recommendations for treatment processes suitable for the specific types of wastewater in Erbil. It emphasizes the importance of establishing a wastewater treatment plant to protect the environment in the area.

1. Introduction

Wastewater can originate from domestic/residential areas, industrial areas, commercial areas, surface runoff, landfill leachate, agricultural activities, infiltration and others (Aziz, 2019). In the current study, different types of wastewaters discharge to sewage system without any treatment except some of new residential areas like Cihan City and Italian-2 City etc. That means a certain rate of wastewater will percolate to groundwater. In many countries, groundwater is an essential water source for domestic, agricultural, and industrial use. In recent decades, demand for freshwater has risen sharply due to the rapid population growth and the fast development of industrialization (Gebrehiwot et al., 2011; Hawez et al., 2020). As a result of the insufficient amount of surface water, the demand for groundwater resources for drinking water, agriculture, and industrial purposes

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multiplied worldwide (Rajappa et al., 2011). Almost thirty percent of the world's population relies on groundwater resources to provide drinking water (Nickson et al., 2005). Groundwater forms 5 % to 7 % of the water resources in Iraq. Several villages, districts, and cities use groundwater as a main source of drinking water and agriculture purpose (Al-ansari et al., 2014). Groundwater has been used recently in the oil and gas sector in Kurdistan Region. Therefore, problems related to groundwater quality and management have to be given further consideration (Hawez et al., 2020). Another rate will evaporate, while the remaining flow of wastewater will discharge into the Greater Zab River, which poses a significant environmental concern. Consequently, industrial, agricultural and rural activities may result in pollution of water courses with elevated trace metal concentrations and implications for water supply and ecosystem functioning.

The disposal of wastewater into the Greater Zab River poses a significant environmental challenge. As wastewater flows are released, a portion of the water evaporates, while the remaining untreated wastewater enters the river system. This discharge risks contaminating the river, harming aquatic ecosystems, and affecting downstream water quality. Addressing this issue is crucial to prevent ecological degradation and ensure the health and safety of communities relying on the river for water resources.

Based on the literature, a gap in knowledge has been identified regarding the effectiveness of the current sewerage infrastructure in Erbil. Specifically, insufficient attention has been given to the lack of a specialized drainage system for storm water management, leading to flooding in residential areas and the discharge of untreated wastewater, which poses risks of groundwater contamination. The objectives of this study were: 1) to assess the shortcomings of Erbil's sewerage system, with particular focus on the interaction between surface runoff and wastewater, and 2) to examine the impact of storm water mixing with untreated wastewater on the environment and reusing of wastewater in Erbil City.

2. Materials and Methods

In the current research both quantitative and qualitative research methods were carried out. Site visits to the different locations in Erbil City were conducted. Interviews/Discussions with the related persons were carried out as well. The characteristics of Erbil municipal wastewater and some collected data were used in this work.

2.1. Study Area

The study area is located at the left side of Erbil-Mosul Main Road at Turaq, which is the main wastewater channel in Erbil City, Figure 1. Erbil municipal wastewater at Turaq commonly consists of wastewaters produces at residential areas like shops and super markets, restaurants, hotels and motels, car washing places, north industrial area, universities and schools, worship places, governmental and administration buildings, private sector houses and buildings, washings, infiltration, and losses of water supply system. Additionally, storm water is mixed with the municipal wastewater during rainy seasons and it dilutes the concentration of pollutants (Aziz, 2020).

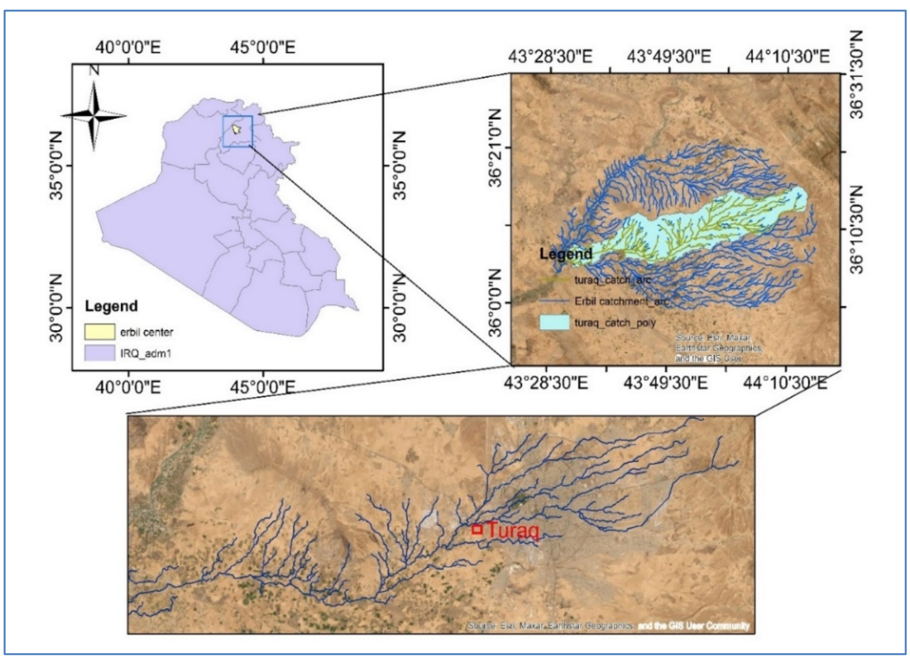

Figure 1. Location of study catchment area

2.2. Site Visiting to Erbil sewage wastewater locations

According to the current situation of the Erbil city sewage system and the directorate of Erbil sewage system, the main problems that occurred due to wastewaters include:

i) the amount of energy consumption that used to treat the wastewater,
ii) wastewater treatment plants also face the problem of a staffing shortage. Efficient and productive workers that are skilled in the business are necessary to properly treat wastewater, and
iii) the environmental footprint left by wastewater treatment plants is smaller and less impactful.

The present section describes the total of nine different site investigations of different positions in Erbil city that has the main problems of surface runoff of wastewaters comes from the various sources in that region. The main problems were clearly explained in the following configurations:

2.2.1. Shewasor Watershed (Kornish Road)

The Shewasur Watershed is located at the east of Erbil City Center, on the right side of the 120-meter main road along Kornish Road. The wastewater in this location is collected behind a designated green space, as illustrated in Figure 2. Some of this effluent contributes to surface water pollution when it flows off the ground. However, remaining wastewater seeps into the soil layers underneath, which could seriously contaminate the nearby groundwater. The region's ecosystem is seriously threatened by these two effects: groundwater contamination and surface water pollution.

Figure 2. Wastewater from Shewasor watershed on Kornish road

2.2.2. Roshanbiry Quarter

The wastewater from this site in Erbil city located near to 120 m-main road. As shown in Figure 3, the wastewater, which mainly comes from households or families, has been discharged into the natural environment without considering the harmful effects on the nature of the region and the health of the population.

Figure 3. Roshanbiry Quarter wastewater

2.2.3. Farmanbaran street

In Farmanbaran street shown in Figure 4 the wastewater was discharged directly into the closed environment without any treatment. In addition to the wastewater, the solid waste from the nearby houses was also removed and disposed of in a landfill. The high concentration of wastewater was to be analyzed during physical, chemical and biological treatment. In some cases, the wastewater was infiltrated through various layers below the ground surface and then discharged out through a well for the purpose of irrigation of an agricultural area.

2.2.4. Zaituna street

The same problem as aforementioned in Farmanbaran street was seen in the Zaituna street. As shown in Figure 5, the amount of wastewater can be seen as a stream inflow over the green geographical region. During long time of wastewater runoff, it may cause the outputting of an excess sludge. The recycling of sludge, containing useful organic matter and nutrients in agriculture is considered as the best solution. Some more modern treatment technologies are even able to reduce the burden of sludge by lowering its production.

Figure 4. Wastewater near from Farmanbaran street

Figure 5. Wastewater near Zaituna street

2.2.5. Altun city

The creation of filtration and treatment facilities for sewage in the Altun City was done as a complex in Erbil. Inside the Altun city, there is a source of wastewater that moves through a number of box culverts and then enteres to a trapezoidal channel at the city itself. This system is old fashion collection of sewages of households that cause many problems since the sewages goes through the city, Figure 6.

Figure 6. Total wastewater inside the Altun City

2.2.6. Turaq area

The big source of Erbil wastewater is the Turaq wastewater, Figure 7. The region impacted by this effluent has a significant water concentration that resembles a long river with distinct upstream and downstream parts. The black water needs the primary and secondary processes of treatment so this huge amount of water can return to the environment. Due to population constantly increasing, municipal wastewater treatment plants need expanding their capabilities.

2.2.7. Cihan city

The domestic wastewater treatment plant for the Cihan city project is finished, Figure 8. There are many different types of waste in the household including; food waste, paper, glass, metals, plastics. Disease, air pollution, and environmental damage can result from domestic waste. Residential waste can be treated using landfills, energy-producing combustion, recycling, and composting. The same configuration was also designed for wastewater treatment system in Italy-2 city.

2.2.8. Bnaslawa District

In some zones, graywater is channeled via the sewage system or transported through unlined canals outside the Bnaslawa district in the south, Figure 9. Later, the channeled wastewater spreads in the environment or enters the Kornish valley. In the rainy season, graywater mixes with stormwater and the mixed wastewater enters the Kornish Valley. In some areas, there are sewer systems with different lengths and different concrete sewer sizes of 0.75 m, 0.9 m, 1.0 m and 1.2 m. In addition, in other zones, box sewers with dimensions of 1.0 m x 1.2 m, 1.5 m x 1.5 m, 2 m x 2 m and 2 m x 2.5 m

Figure 7. Erbil wastewater at Turaq area

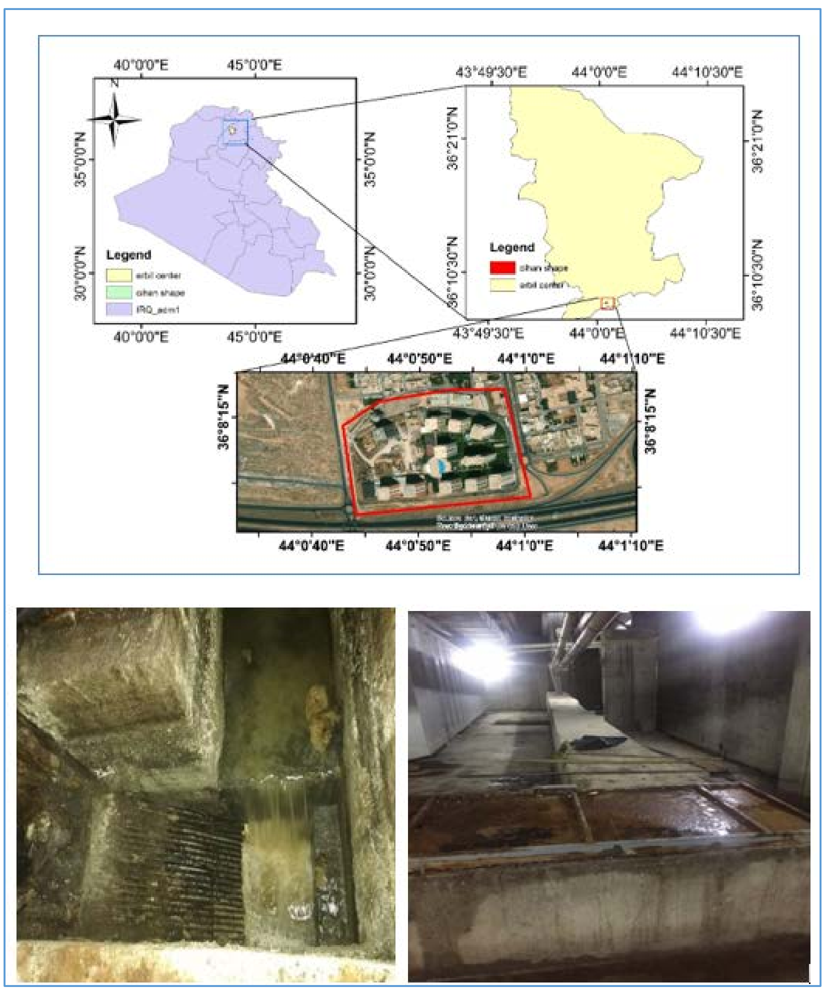

Figure 8. Wastewater treatment in Cihan city

Figure 9. Wastewater conveying by sewerage system and unlined channel

are available in different lengths. Black wastewater is normally treated in cesspools. About 2 % of black wastewater is illegally connected to the sewage system.

3. Results and Discussions

3.1. Quality of Wastewater in Erbil City

Life style, season, sewerage system, climate, and areas (or zones) had effect on the quality of the wastewater. Previous research has concluded that Erbil's wastewater is unsuitable for irrigation in all cases. For instance, (Aziz et al., 2019) specifically stated that Erbil's wastewater should not be used directly for irrigation purposes. Mainly, the treatment of Erbil municipal wastewater using various systems may lead to decrease of contaminants such as; organic matter, suspended solids, nitrogen compounds etc. As a result, treated wastewater can be used for the irrigation purpose. The produced wastewater from Bnaslawa district can be considered as weak wastewater and can be treated in wetlands and aerated lagoons (Aziz, 2024). Erbil municipal wastewater has been observed to be (weak/low to medium) wastewater type according to Aziz, (2020) and this found BOD5 values of (6.3 mg/L to 304 mg/L) for EMWW Erbil municipal waste water which is in agreement with published data. Lower COD values were reported in a number of South Korean Wastewater Treatment Plants by Choi et al. (2017). Similarly, lower BOD_5, COD, TSS, PO_4, NO_3-N, and NO_2-N for two municipal wastewater treatment plants in Indonesia. On the other hand, lower BOD_5, COD, NO_3-N, NO_2-N, and turbidity values for MWW Municipal waste water in there WWTPs Waste water treatment plants in Malysia (Aziz, 2020). The literature highlights variations in wastewater quality across different countries, emphasizing the importance of considering these differences when designing a centralized wastewater treatment plant for Erbil. Understanding these variations is crucial, as it helps ensure that treatment processes are tailored to address the specific characteristics and contaminants present in Erbil's wastewater, leading to more effective and efficient treatment solutions.

Fluctuations were noticed in the Erbil municipal wastewater quality and time had not great effect on EMWW characteristics. The causes of increasing discharge may refer to increase in human generation, leakage in water distribution system, expansion of size of the city and sewerage system, and additional storm water. It should be considered that the mixing of storm water and municipal wastewater caused the dilution of Erbil municipal wastewater, especially during rainy seasons.

The study also observed that the biological problems are available in EMWW; for these reasons both (treatment and disinfection) processes are necessary. In spite of this, the nutrients such as (organic matter, nitrogen compounds, and phosphate) are present in Erbil municipal wastewater, which can be used for agriculture and irrigation purposes. Also, heavy metals such as (Cd, Cu, Zn, and Pb) were found in Erbil municipal wastewater that exceeded the standard limitations of Wastewater discharge that needs extra treatments (Aziz, 2020). Usually, Disinfection process is required to eliminate biological problems. Based on the existence of oil and grease, PO_4, Mg, and Ca values for Erbil municipal wastewater, reclaimed Erbil municipal wastewater can be used for irrigation according to the standards., the details of the Erbil wastewater characteristics are tabulated from Table (1 to 3) (Aziz, 2020). Additionally, Characteristics of Ashty City wastewater are given in Table 4.

Table 1
Characteristics of Erbil Erbil municipal wastewater -Part 1 (Aziz, 2020)

Parameters	Range	Standards
pH	6.1-8.85	6-9.5*
Temp.(C)	10-31.5	35*,40**
EC(μs/cm)	284-2,300	
T.Salts(mg/L)	236.8-1,800	
TS(mg/L)	300-10,000	

Table 1 Continued
Characteristics of Erbil Erbil municipal wastewater - Part 1 (Aziz, 2020)

Parameters	Range	Standards
TSS (mg/l)	40-1,800	60*, 35**
TDS (mg/l)	100-8,200	
Turbidity(NTU)	0.41-1,000	
chloride	0.86-165	
T.Acidity(mg/L)	0.18-60	750**
T.Hardness(mg/L)	120-590	

*: Iraqi Environmental Standard (2011) (Aziz, 2020).
**: Environmental protection regulations (EPA) (2003) (Aziz, 2020).

Table 2
Characteristics of Erbil municipal wastewater - Part 2 (Aziz, 2020)

Parameters	Range	Standards
BOD_5 (mg/L)	6.3-304	40*
COD (mg/L)	12.2-901	100*
NH_3–N (mg/L)	0.004-11.4	Nil*, 1 **
NO_2–N (mg/L)	0.001-26	1 **
NO_3–N (mg/L)	0.003-47	50*, 10**
SO4 (mh/L)	0.008-1220	1500**
DO (mg/L)	0-10.4	
PO_4 (µg/L)	0.0015-6.97	3*
Na (%)	6.1-73	
SAR (%)	0.19-16	
Total coliform cell/100 ml X 105	0.34-380	

*: Iraqi Environmental Standard (2011) (Aziz, 2020)
**: Environmental Protection Regulations (EPA) (2003) (Aziz, 2020)

Table 3
Characteristics of Erbil municipal wastewater - Part 3 (Aziz, 2020)

Parameter	Value	Range	Standard
Na (mg/L)	30.6 - 32.1 0.38 - 2.3 62	0.38 - 62	
Ca (mg/L)	5.4 - 6.4 1.8 - 4.8 85	1.8 - 85	
Mg (mg/L)	2.8 - 3.4 0.1 - 0.42 30.8	0.1 - 30.8	0.5*
Cd (mg/L)	0 - 46.73	0 - 46.73	0.01*
Cu (mg/L)	0 - 18.69	0 - 18.69	0.2*
Zn (mg/L)	0 - 76.92	0 - 76.92	0.2*
Pb (mg/L)	0 - 61.76	0 - 61.76	0.1*
TVS (mg/L)	206.8 100 - 300	100 - 300	
TnVS (mg/L)	227.9 100 - 600	100 - 600	
BOD_5/COD	0.487-0.830	0.487 - 0.830	
Color (Pt.Co,)	186 - 379	186 - 379	Nil *
Mn (mg/L)	1.3 - 4.6	1.3 - 4.6	0.2
TOC (mg/L	19 - 180	19 - 180	
Phenols (mg/L)	0.044 - 0.102	0.044 - 0.102	0.01 - 0.05*
Oil & grease (mg/L)	0.04 - 1.05	0.04 - 1.05	Nil*, 10 **
ORP (Mv)	-74.2	-107.4 - (-33.2)	
Salinity	0.26 - 057	0.26 - 057	
T. Alkalinity (mg/L)	260 - 340 157.3 - 236 206 301	157.3 - 340	
Alkalinity (%)	17.67 - 19.11 8.93 - 40.15	8.93 - 40.15	
TVC Bacteria (Cfu/mL)	$110 \cdot 10^5$- $176 \cdot 10^5$	$110 \cdot 10^5$- $176 \cdot 10^5$	

Table 3 Continued
Characteristics of Erbil municipal wastewater - Part 3 (Aziz, 2020)

Parameter	Value	Range	Standard
Phytoplankton density	21,787.5	21,787.5	
Total Bacteria Count (X10^8)	0.002 - 0.74	0.002 - 0.74	
Total bacteria cell/L x l0^5	0.047 - 77 0.87 - 193	0.047 - 193	
Total fungi cells/L X 10^4	0.49 - 107.5 0.035 - 240	0.035 - 240	
Discharge (m^3/s)	0.85 - 1.7 1.23 - 2.61 1.696 - 3.582 5.56	0.85 - 5.56	

*: Iraqi Environmental Standard (2011) (Aziz, 2020)
**: Environmental protection regulations (EPA) (2003) (Aziz, 2020)

Table 4
Ashty City WW characteristics (Aziz et al., 2020)

No.	Parameter	Unit	Value 25 Feb. 2018	Value 27 March 2018	Disposing standards
1	pH		8.2	8.6	6.5 - 9.6*
2	Temperature	°C	14	14.9	<35*, 40**
3	EC	µs/cm	500	417.2	
4	Turbidity	FTU	18	20	
5	Total Acidity	mg/L	20	20	
6	Total Alkalinity	mg/L	200	212	
7	Total Hardness	mg/L	116	136	
8	Chloride	mg/L	26	24	750 **
9	Colour	Pt. Co	157	103	Nil *
10	Total salts	mg/L	300	267	
11	Total solids	mg/L	300	600	
12	TDS	mg/L	100	200	
13	Total Suspended Solids	mg/L	200	200	60*, 35**
14	Total non-volatile solids	mg/L	200	500	
15	Total non-volatile solids	mg/L	100	100	
16	BOD_5	mg/L	100	95	<40*
17	COD	mg/L	200	196	<100*
18	BOD_5/COD		0.5	0.48	
19	ORP	mv	-111.2	-131.3	
20	Ammonia	mg/L	7	7.2	Nil*, 1 **
21	DO	mg/L	5.6	5.3	
22	Nitrate (NO_3-N)	mg/L	4.1	3.5	50*, 10**
23	Nitrite (NO_2-N)	mg/L	8	9	1 **

*: Iraqi Environmental Standards (2011) (Aziz, 2020)
**: Environmental protection regulations (EPA) (2003) (Aziz, 2020)

3.2. Evaluation of Erbil sewerage system

3.2.1. Overview

Sewerage system from Erbil city conveys both sewage and stormwater into the downstream valleys of Erbil, eventually flowing into the Greater-Zab River. The city lacks a centralized wastewater treatment plant. According to the study by Mahmood (2020) the sewer network system extends to a length of 24 km. In general, the sewer network is composed of sewer lines, manholes, and inlets. First, sewer lines include both box and pipe lines of various sizes and construction materials. These materials range from ordinary concrete and reinforced concrete to different kinds of plastics, polyethylene, steel, cast iron, and ductile iron. The sizes of the box and pipe sewer lines vary, starting form a 20 cm diameter and going up to 3m by 3m for box sewers. Typically, smaller sewer lines are referred to as branches, larger ones as main sewers, and those in between as sub-mains. Second, manholes are built into both box and pipe sewer lines for purposes such as maintenance, and for facilitating bends and connections. Finally, inlets are used to collect wastewater. The sewer networks function entirely by gravity, hence the term "gravity sewer network", which is one of the oldest and most common types worldwide. Concerning the types of wastewaters, it generally includes stormwater and graywater, which are collected and transported by the sewer system to the drainage point (Ameen and Aziz, 2024a).

3.2.2. Septic tank and Cesspools

Cesspools and septic tanks are generally used for managing blackwater in Erbil City. Houses typically rely on cesspools, while both cesspools and septic tanks are utilized for schools, mosques, markets, and similar establishments. This practice has led to ground water issues, such as contamination with nitrate and nitrite. Recently, in response to new local government regulations, some compact units and small-scale wastewater treatment plants have been built, such as in Italy city 2 and Cihan city etc. Some of these facilities reuse treated wastewater for irrigation, particularly for landscaping and green zones (Ameen and Aziz, 2024a; 2024b). Additionally, the Ministry of Municipality plans to build a large-scale central wastewater treatment plant in Turaq valley. Currently, the groundwater table has significantly decreased as Erbil has developed rapidly, with a corresponding rise in population and water demand. The government is now focusing on the sewage system for reuse purposes and as an additional water source.

Blackwater from toilets is generally disposed to the cesspools in Erbil City. This cesspool is regularly lined with stone, concrete or brick and received the BW Blackwater and needs emptying at regular intervals, dependent upon the size of the tank, the number of people living at the property, and characteristics of the soil. Sometimes these holes allow waste seeping to the ground and it will be source of soil and groundwater pollution and consequently effect on human health and environment. The main problem in Erbil City there is no any kind of treatment for this wastewater. In general, the treatment in cesspool is very low and it could be considered as a primary settling tank where solids and liquids separate and also biological process will be there. The settling process happens via gravity and a primary colony of bacteria digests the organic waste. Anaerobic digestion is considered one of the oldest technologies applied to treat wastewater. The main advantages of anaerobic digestion are biogas production and less amount of sludge production compared to aerobic treatment. Furthermore, it plays an important role in water management like reducing the consumption of high-quality drinking water, safe sanitation since the hazardous compounds in blackwater will not spread in the water cycle, production of biogas for domestics uses such as cooking, lighting ...etc. In addition, it produces organic fertilizer that is used in agriculture field. One of the major health hazards in many countries is the lack of sewer system and an efficient wastewater treatment plant, therefore the municipal wastewater and blackwater discharged directly to the environment (Alrawi et al., 2021)

3.2.3. Separate and Combine Systems

In sanitary engineering, the sewerage network is mainly divided into two types, namely a separate system and a combined system. Both types collect all types of wastewaters, i.e. rainwater, graywater and blackwater, as well as industrial and commercial wastewater. Consequently, household and other types of connections cannot be effectively implemented due to the lack of sewer branches throughout the area. This situation leads to several issues, including health risks from pathogen exposure, persistent odor problems, and the need for frequent municipal cleaning. Ideally, stormwater should flow into designated inlets, while houses and other structures should be properly connected to the sewer network to prevent these problems.

3.2.4. Current Situation

The current sewage system in Erbil remains incomplete. The city lacks a wastewater treatment plant, and the system is neither fully combined nor separate. It operates as a stormwater sewer system, which is inadequate for a city of Erbil's size. Additionally, the network has several well points that become problematic during heavy rains, such as in Gilkand quarter near Langa Bazar, 100 m street near Akar oil station, Tayrawa near Bayz interaction, and under the Saydawa bridge. Some sections of the sewer system are completely or nearly blocked, particularly in areas like downtown, Shekh Alla, Badawa, Setaqan, and some parts of 30 m street. The entire sewage system also suffers from a lack of maintenance, including in manholes and inlets. Currently, untreated sewage is sometimes used for irrigation during the summer season, transported by tankers.

Finally, the sewer network in Erbil is primarily a gravity sewer system, with the majority consisting of pipe sewers and a smaller portion made up of box sewers. Concrete, both ordinary and reinforced, is the most commonly used construction material, followed by plastic and polyethylene, with steel and iron being used to a lesser extent. Polyethylene is currently the preferred material in sewage projects due to its advantages, though it also has drawbacks. Topography plays a crucial role in the system, as the slope directly influences the velocity within the sewer lines, affecting sedimentation. Proper household connections or connections from any structure to the sewer network are essential to avoid the issues mentioned earlier. Additionally, wastewater can be reused for various purposes, which supports surface and subsurface water sources as part of the water supply system (Ameen and Aziz, 2024a; 2024b).

3.3. Quantity of Wastewater

Quantity of municipal wastewater in the main channel at Turaq area from 2001 to 2020 varies between 0.85 m^3/s to 5.56 m^3/s (Aziz, 2020). Expected total amount of produced wastewater in Erbil City can be calculated as follow:

No. of Population in Erbil City in 2020 = 846,000 Capita (Ismael and Aziz, 2024a)

Water supply per capita = 380 LPCD (Ismael and Aziz, 2024a)

80 % of water supply becomes wastewater.

Total quantity of wastewater = 846,000 Capita x 380 LPC x 0.8 = 257,184,000 L/day = 257184 m^3/day

Suppose each square meter needs 20 L for irrigation,

Irrigated area = 257,184,000 L/day ÷ 20 L/m^2 = 12,859,200 m^2/day = 5143. 68 donums/day = 5,143,680 m^2/day

3.4. Impact of the Wastewater on the Environment

Municipal solid waste (MSW) disposal systems include open dumping, sanitary landfill, composting, and incineration. Sanitary landfill is the best public MSW disposal technique because of easy disposal method, low budget, and landscape-restoring effect on holes from mineral workings. However, the production of highly contaminated landfill leachate is a chief shortcoming of this technique. Gas and inert solids comprise other products of landfills. Leachates may contain large quantities of organic pollutants, nitrogen compounds (e.g., ammonia), suspended solids, heavy metals, inorganic salts, phenols, and phosphorus (Maulood and Aziz, 2016). According to the Erbil sewerage system, the surface runoff of storm rainfall mixes with wastewater. The lack of a special designed drainage system dependent on the quantities of water coming from rainstorms means that manholes are unable to draw rain quantities and some of residential areas will be flooded. Thus, the current wastewater management system in Erbil is inadequate, as untreated wastewater from various sources is discharged directly into the sewage system, leading to potential groundwater contamination. Alrawi et al. (2021) stated that direct disposal of the blackwater to the environment caused pollution for the municipal wastewater and the surrounded soil.

3.5. Reusing

Wastewater reuse afterward appropriate treatment can positively help resolve the emergency situations that may occur in areas with inadequate water resources. Industrial, municipal, and household wastewaters can be reused. Reusing is allowed, provided that complete environmental safety is guaranteed and that any health hazards to the local population are removed. This requires strict compliance with existing health and safety regulations and with agricultural and industrial legislation. When reusing municipal wastewater, a general distinction is made between indirect and direct reuse. Direct reuse of treated wastewater for drinking water is not currently a practical option because of health risks and availability of water resources in the selected area. Indirect reuse is applied when the treated wastewater is used for dilution and purification after being returned to normal water sources. It includes natural buffers for further spatial and temporal separation of treatment (Ismael and Aziz, 2024b; Ismael et al., 2024). The authors described that Erbil City's wastewater is no longer safe for all kinds of irrigation before treatment. They found that Erbil municipal wastewater is suitable for cooked vegetables and irrigation of green areas. Treatment techniques are vital for the earlier disposal of wastewater to the surroundings or the use for irrigation purposes. In the functions of wastewater, the treatment processes were studied along with primary, secondary and tertiary treatment. Additionally, municipal wastewater with appropriate treatment, the practice of separate approaches and the suitability of treated wastewater for disposal to the plant environment or use for irrigation purposes were investigated (Ismael and Aziz, 2024b; Ismael et al., 2024).

4. Conclusions

The absence of a centralized wastewater treatment plant has led to significant environmental challenges, including groundwater contamination and inadequate sewage management. The sewage system, which functions primarily as a gravity sewer system, is incomplete and inadequately equipped to meet the city's needs, especially during heavy rainfall. In addition, the improper use of untreated wastewater for irrigation poses serious health and environmental risks. The study highlights the need for improved sewage infrastructure, including proper household connections, the construction of a large-scale wastewater treatment plant, and the adaptation of sustainable wastewater reuse practices to support water resources. The condition of the sewerage infrastructure was assessed, and areas in need of improvement were identified. The quality and quantity of wastewater was thoroughly analyzed, highlighting the main issues related to treatment and potential risks. In addition, the possibilities for wastewater reuse were investigated, highlighting opportunities for sustainable water management. It was found that urgent actions and improvements are needed to improve the efficiency, safety and sustainability of Erbil's wastewater system. The total wastewater volume and irrigated area are 257,184 m^3/day and 5,143,680 m^2/day respectively.

Based on the findings, several measures are recommended to address the critical problems in Erbil's sewage system. A centralized wastewater treatment plant should be built to mitigate the environmental problems, including groundwater pollution. Proper household connections need to be established to ensure full integration of the gravity sewer network. Sustainable wastewater reuse practices also need to be introduced to reduce dependence on untreated wastewater for irrigation.

These measures should be prioritized to improve the city's wastewater management system, especially in light of rapid population growth and development. By implementing these recommendations, environmental protection and public health in Erbil can be ensured in the long term. It is important to consider the following points for future study:

- Construction of a large centralized wastewater treatment plant for the city of Erbil,
- Use of sulfate-resistant cement for concrete and increased use of polyethylene (PE) and glass fiber reinforced plastic (GRP) pipes,
- Increasing the safety factor for the capacity and dimensioning of sewer pipes and boxes, which means that they function very well during floods or rainy days, especially in spring and winter,
- The layout of the sewer pipes is also an important natural valley that must be taken into account during planning and construction,
- Continuous maintenance of the sewers is important to ensure that they do not clog and function well at all times, Compact units to be built for each type of project, as well as the installation of strainers and grease interceptors (FOG), e.g. in restaurants,
- Avoid deep excavations for wastewater pipes and use other alternatives.

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Procena kanalizacionog sistema i uticaja otpadnih voda na životnu sredinu i njihovo ponovno korišćenje u gradu Erbil

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Kanalizacioni sistem
Otpadne vode

I Z V O D

Ova studija pruža sveobuhvatnu procenu kanalizacionog sistema u gradu Erbil, Irak, sa fokusom na kvalitet i količinu otpadnih voda, kao i na uticaj ispuštanja neprečišćenih otpadnih voda na životnu sredinu. Grad nema centralizovanu fabriku za prečišćavanje otpadnih voda, iako je njen projekat već odobren. Studija procenjuje trenutni sistem poređenjem postojećih podataka sa prethodnim istraživanjima, naglašavajući uticaj načina života na karakteristike otpadnih voda u regionu. U radu se ističu opasnosti od ponovnog korišćenja neprečišćenih otpadnih voda za navodnjavanje, koje predstavlja značajne zdravstvene i ekološke rizike, uključujući kontaminaciju podzemnih voda. Podaci su prikupljeni kroz posete različitim lokacijama u gradu Erbil. Istraživanje razmatra trenutne i potencijalne uticaje otpadnih voda na vodotoke. Utvrđeno je da se većina otpadnih voda u Erbilu ispušta neprečišćena u životnu sredinu, uzrokujući ozbiljne probleme sa zagađenjem. Ukupna količina proizvedene otpadne vode i navodnjavane površine iznosi 257184 m^3/dan i 5143680 m^2/dan. Pored toga, u radu se nalazi i preporuka za procese prečišćavanja koji su pogodni za specifične vrste otpadnih voda u Erbilu. Naglašava se važnost uspostavljanja fabrike za prečišćavanje otpadnih voda radi zaštite životne sredine u ovom području.

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