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ENGINEERS' AND ARCHITECTS' PERCEPTIONS OF THE ENVIRONMENTAL POLLUTION CAUSED BY CONSTRUCTION SITES IN THE CITY OF BUJUMBURA

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ABSTRACT

Despite the necessity for humans to enhance their well-being and development, the process of improving one's own quality of life has inadvertently resulted in the destruction of some of the fundamental components of biodiversity that are essential for human existence, whether directly or indirectly. The objective of this study is to enhance comprehension of the detrimental consequences of construction on the environment. This will be achieved by delineating the various forms of pollution and proposing strategies to mitigate these impacts. Additionally, the study will gather information from

engineers and architects. This study proposes that intensifying educational efforts with companies to improve practices in the field would be advantageous. The absence of skips on some building sites demonstrates an urgent need to enhance waste management infrastructure in response to the tightening of environmental regulations. It would be prudent to promote collaboration between government entities, construction stakeholders, and local communities to develop sustainable solutions that are tailored to the specific needs and circumstances of each region. This research was constrained by the unavailability of essential equipment for measuring noise, air, and water pollution on site, which could have enhanced the accuracy of the perceptions of the people interviewed. It would be beneficial to supplement this survey with broader studies and the opinions of other stakeholders. Furthermore, the scarcity of publications and research conducted in Burundi on related subjects further limited the scope of this study.

Keywords: Pollution, construction site, environment, impact, sustainability, Bujumbura

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1. INTRODUCTION

The issue environmental degradation represents one of the most urgent global concerns [1]. The current state of environmental degradation is the result of a multitude of factors that exert a complex and varied impact on the natural environment [2]. Globally,pollution levels exceed the standards set by the World Health Organization (WHO), with adverse effects on human health and the integrity of ecosystems [3]. Urbanization, rapid population concentration, and development in urban areas have profound effects on the environment [4]. In order to ensure the sustainability of urban areas, it is necessary to pursue sustainable development in accordance with the Sustainable Development Goals (SDGs)[5].

The construction industry is a primary source of global environmental impact, with a notable consumption of raw materials, energy, waste production, and greenhouse gas emissions [5]. The materials utilized also exert a considerable influence, including the energy expended during the manufacturing process [6]. In a construction project, every aspect has an evident impact. For instance, in order to build, engineers must clear the site of trees, which has the effect of damaging the site's environmental balance [7]. On a global scale, the construction sector is responsible for 23% of air pollution, 40% of drinking water pollution, and 50% of landfill waste [8]. In the United States, buildings are responsible for the release of over 2,200 megatons (Mt) of carbon dioxide (CO_2) into the atmosphere annually, representing approximately 35% of the country's total emissions [9]. In Europe, buildings account for approximately 40% of energy consumption and over 50% of gas consumption, and are also responsible for 35% of energy-related greenhouse gas emissions [10]. within the United Kingdom, the construction sector is responsible for 45% of carbon emissions [11]. In 2014, the construction industry generated 202.8 million tons of waste, of within 59% was created by the construction industry itself [8]. With regard to global energy demand, the African continent is responsible for approximately 6%, with more than half of this figure being derived from buildings [12]. In France, the construction and public works sector is the primary generator of waste [13]. In Spain, environmental monitoring is compulsory for all activities included in the regulations governing environmental impact assessments [14].

Since the early 2000s, the city of Bujumbura in Burundi has undergone a period of remarkable expansion. Nevertheless, this expansion has not been accompanied by the requisite adherence to urban planning standards. Indeed, there has been an observable trend of housing construction on undeveloped land, with a notable absence of adherence to the relevant regulatory frameworks [15]. At this juncture, it is imperative to acknowledge that the prevailing legislation governing the construction sector in Burundi is not being adhered to. However, the existing regulatory framework has inherent limitations with regard to sustainability. Consequently, there is an imperative for the enhancement of these regulations to promote environmentally sustainable practices in the Burundian construction industry [16]. Unfortunately, as populations continue to migrate to urban centers, demand for resources, infrastructure and services increases, exerting significant pressure on natural ecosystems [4].

A review of the extant literature reveals a number of adverse health effects associated with exposure to construction sites and construction workers. These include ocular irritation, asthma, bronchitis, lung damage, cancer, heavy metal poisoning, and cardiovascular effects leading to premature mortality [7]. The construction industry has the potential to play an

instrumental role in preserving our planet for future generations. The advent of new technologies has rendered it feasible to address fundamental human needs, including housing, transportation, and the development of efficient health and education infrastructure [17]. Consequently, the question arises as to the various types of environmental pollution generated by construction sites in Bujumbura and their impact on the local environment. The construction sector is one of the most impactful, yet it also represents a source of potential solutions. In the contemporary context, characterized by mounting environmental consciousness, the construction of sustainable buildings has emerged as a paramount objective for developers, architects and end users. In this context, environmental certifications for sustainable buildings, such as LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method) and HQE (High Environmental Quality), have emerged as the prevailing standard [18].

The Building Research Establishment (BRE) initiated the Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom in 1990. The method has since been adopted in over 80 countries worldwide. Additionally, the certification has been accessible in France since 2013 [19]. A further study by Dodge Data & Analytics indicates that green buildings have lower operating costs, which is regarded as the most significant advantage of green buildings [20].

In Burundi, there is a paucity of educational resources concerning green building techniques, as well as a dearth of adaptation of current regulations to effectively address environmental concerns in the construction sector [21]. It is therefore imperative to implement sustainable construction practices with the objective of comprehending the various forms of pollution in order to more effectively identify potential solutions for mitigating the adverse effects of construction on the urban environment in Bujumbura, as well as control and prevention measures. A proactive and responsible approach will not only preserve the environment, but also facilitate sustainable economic growth that respects nature.

2. LITERATURE REVIEW

2.1 The Environmental Impact of Construction

The construction sector is considered a major contributor to environmental degradation. It is responsible for approximately 20-50% of global natural resource consumption, 50% of carbon emissions and 50% of total solid waste [22]. The industry is regarded as one of the most significant consumers of both renewable and non-renewable natural resources. The industry is

considered one of the largest consumers of both renewable and non-renewable natural resources. The industry relies heavily on the environment as a source of raw materials, including aggregates, sand and wood. As noted by [23],the construction sector is responsible for consuming 40% of the world's raw stone, gravel and sand and 25% of virgin timber annually. The production of construction materials, including steel, aluminum, concrete, cement, chemicals, glass and plastics, typically involves the use of a combination of natural resources, which can have a negative impact on the environment due to the extraction and manufacturing processes involved [24].

The construction sector has been identified as having significant environmental impacts, including pollution and greenhouse gas (GHG) emissions resulting from the transport and processing of materials used in construction activities [22], [24]. According to the United Nations Environment Program [12], [25], construction activities were responsible for 20% of global energy-related carbon dioxide (CO2) emissions in 2020. Construction activities have the potential to generate a considerable amount of dust, including during processes such as cement and concrete mixing, template cutting, sandblasting, rock drilling/grinding, and masonry work. This dust has the potential to have a detrimental impact on the surrounding environment and is regarded as a significant health hazard[26], [27], [28]. The consequences of construction dust on the local environment and on human health and safety have become a matter of public health concern. For instance, studies have shown that dust from construction activities, particularly silica dust, has been demonstrated to have an adverse impact on the health of residents and construction workers on site. Even limited exposure over a relatively brief period can result in the onset of silicosis [26], [29].

The noise generated by construction activities represents one of the most significant acoustic pollutants in communities, as all citizens are exposed to elevated levels of noise, not just construction workers [28], [30], [31]. The etiology of noise pollution emanating from construction activities is conventionally ascribed to three primary sources: namely, site traffic, the operation of noisy tools and equipment, and the direct involvement of high-noise machinery, particularly in earthworks comprising site clearing, excavation, cutting, filling, and compaction [32], [33], [34]. Noise pollution represents a significant hazard on construction sites, with the potential to cause serious damage to the health and safety of workers and the neighbouring community [32], [35]. Noise-induced hearing loss is recognized as the most pervasive and irreversible occupational hazard in the construction sector [36]. Consequently, noise exposure can have a detrimental effect on the social, psychological and physical well-being of individuals residing in proximity to construction activities and construction workers.

The construction sector is responsible for the generation of waste throughout the construction project, from the initial design phase to the final stage of completion. This waste has a detrimental impact on the environment, including soil, air and water pollution [37], [38] . The composition of construction waste is dominated by inert, non-biodegradable materials, including concrete, plaster, masonry, non-ferrous metals, paper, cardboard, mortar, bricks, tiles, glass, paints, pipes and electrical appliances, wood and plastics. The recycling of these materials is hindered by the presence of contaminants and the heterogeneity of the materials, which makes them difficult to process [39]. The predominant method for waste disposal is the placement of waste in landfills [40], [41]. However, the utilization of landfills for waste disposal is unsustainable, due to the limited space available and the quantity of waste generated.

The impact of construction activities on the ecosystem is one of the most significant environmental impacts [42]. The use of land for construction purposes results in the removal of natural habitats, which has a significant impact on biodiversity and contributes to habitat loss [43], [44], [45]. This leads to a reduction in the quality of biodiversity below its natural state due to the alteration of ecosystems on which biodiversity depends at that particular construction site [46], [47]. In addition, the use of heavy earthmoving equipment and vehicle traffic can result in increased runoff due to topsoil compaction. This can lead to increased sediment loads in nearby water bodies. Water pollution from construction sites can negatively affect the environment and the economic and social well-being of the population due to its impact on the ecosystem [48].

3.MATERIALS AND METHODS.

Bujumbura is Burundi's main urban center. Since 2018, it has also served as the country's main economic hub and a prominent academic center. Situated to the north-east of Lake Tanganyika, the city was founded by the Germans in 1896 for administrative purposes. Bujumbura's history shows that, until the early 1980s, the urban municipality was located within the present boundaries of the Mukaza municipality. Bujumbura is located between 3°30' and 3°51' south of the equator and between 29°31' and 29°42' east of the prime meridian. The city covers an area of 10,462 hectares and is divided into three municipalities: Muha in the south, Mukaza in the center and Ntahangwa in the north, which are subdivided into 13 administrative units organized as urban zones [49].

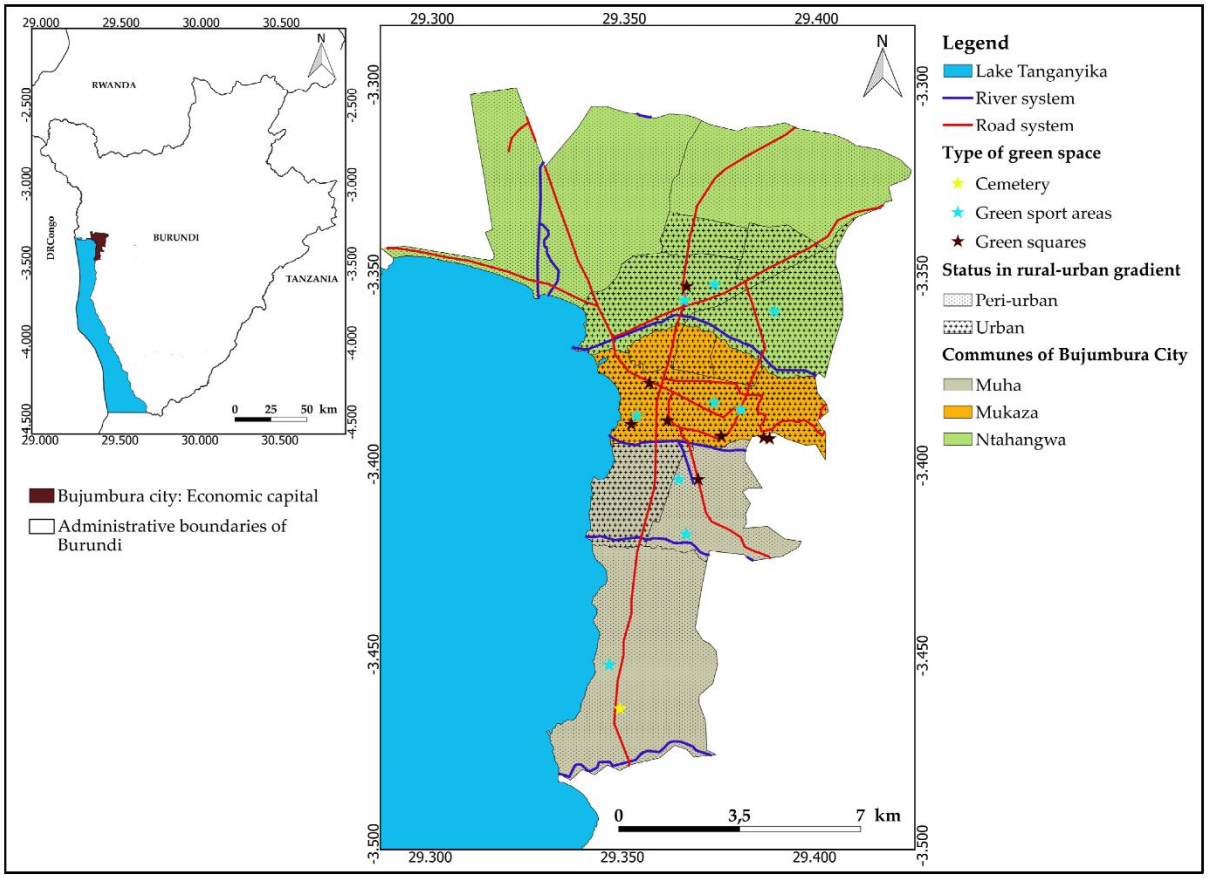

Figure 1: Map of the study area and location of the three urban municipalities of the city of Bujumbura, produced using ArcGIS software.

To obtain the necessary data, an anonymous survey questionnaire was sent to local engineers and architects in the city of Bujumbura. Responses to the online survey were automatically collected using Kobo-collect software, and the summary of responses was downloaded into an Excel file for analysis and graphing. A total of 145 respondents took part in the survey. The research used a combination of quantitative and qualitative methods. Respondents were asked to provide answers in relation to projects involving different types of pollution caused by construction sites.

4.RESULTATS AND DISCUSSIONS.

This survey of 145 respondents sought to understand the perceptions of key stakeholders in the construction industry regarding the environmental impact of construction sites. The results of the eleven questions indicate a high level of awareness and a growing interest in construction-related environmental issues.

4.1. General awareness of respondents

The majority of respondents indicated that they were aware of the potential environmental impacts of construction sites, with 98.6% acknowledging their capacity to cause pollution. This finding suggests a general awareness of the sector's negative environmental implications.Additionally, [50] has demonstrated in his research that new buildings and facilities can contribute to significant air pollution due to construction work. Additionally, [51] acknowledges that excessive noise pollution can lead to increased blood pressure and hearing loss in residents near construction sites.The two respondents who answered "no" (representing 1.4%) may lack sufficient knowledge of the environmental effects of construction or may not perceive these impacts as significant.

4.2. Interest in preventing the environment during construction phase

The following graph illustrates the interest in preventing the environment during the construction phase according to the responses of the informants.

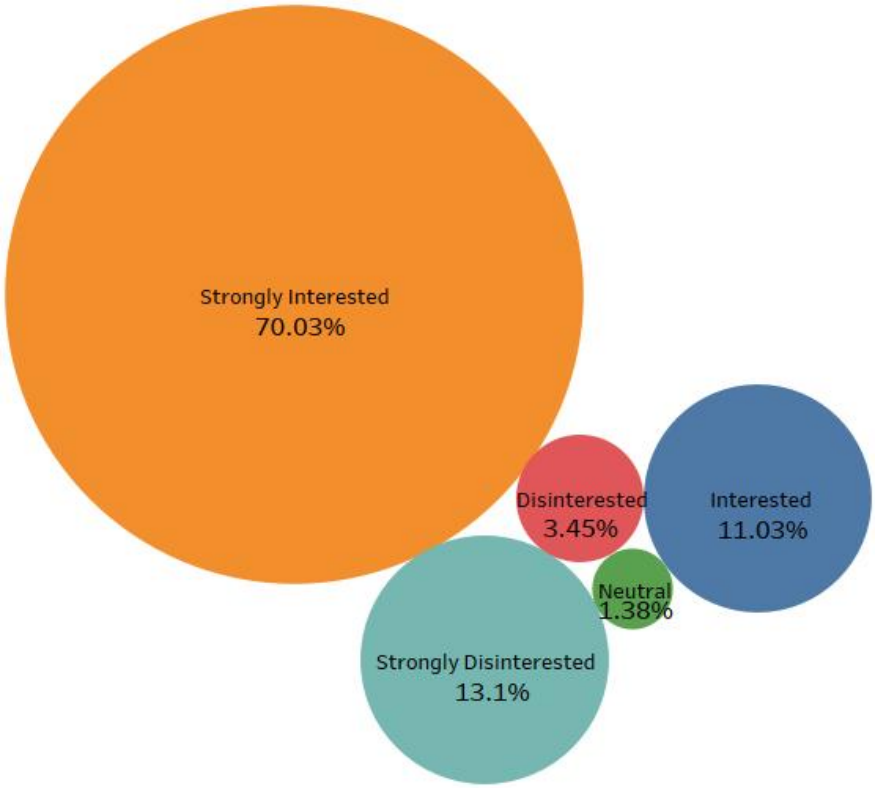

Figure 2 : Illustration of the interest in preserving the environment during the construction phase

Figure 2 demonstrates that the majority of respondents expressed a considerable degree of interest in environmental preservation during the construction phase, with 71.0% of

respondents indicating a high level of interest or engagement. [52] sustains a similar viewpoint, stating that a series of precautions must be implemented during the site organization phase, with the objective of limiting any potentially problematic impacts, including noise, vibrations, dust, water pollution, and so forth. The planning of the various stages will be based on the biological rhythms of endemic species, with consideration given to nesting or breeding, hibernation or flowering periods. This reflects a growing awareness of the importance of sustainability in the construction sector. However, a minority of respondents appear less concerned or indifferent, suggesting potential differences in opinion regarding the significance of environmental protection or varying priorities among different groups. Nonetheless, the construction sector possesses the capacity to forge a future where progress and clean air coexist. This can be accomplished by employing not only more sustainable materials but also strict regulations and innovative technologies to pursue a harmonious balance between development and environmental preservation [50].

4.3. Presence of waste collection facilities on the site

This study was also conducted to ascertain the presence of waste collection tools, such as dustbins, on construction sites. The survey revealed three predominant categories: i) 46.9% of respondents indicated that their construction sites lacked such facilities, ii) 36.66% of respondents confirmed the presence of these facilities, and iii) 16.55% of respondents expressed uncertainty.

The management of waste is of paramount importance in order to limit pollution. The absence of adequate skips could indicate a deficiency in construction site practice [50]. [53],the utilization of skips for on-site collection is intended to prevent the mixing of different categories of waste and thus facilitate their sorting.The proportion of respondents who were unsure (16.55%) may also suggest a lack of knowledge regarding practices on certain sites, underscoring the need to strengthen waste management practices on construction sites. The finding that 25% of respondents expressed uncertainty regarding the presence of skips on their premises underscores the necessity for the implementation of waste management systems.

4.4. Frequency of environmental pollutants associated with construction projects

The following graph presents the most prevalent categories of environmental pollutants attributed to construction projects, as identified by surveyed respondents.

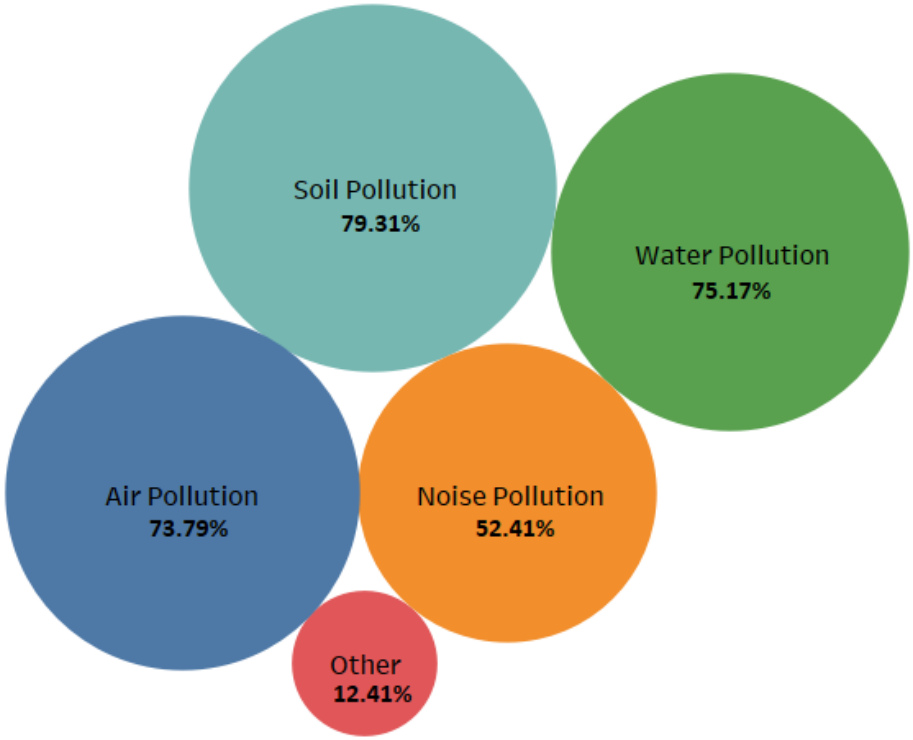

Figure 3 : Perception of environmental pollutions that could result from construction projects.

As demonstrated in Figure 3, the most frequently referenced forms of pollution are soil, water, and air. This observation serves to reinforce the notion that the ramifications of construction sites are manifold and pervade disparate facets of the natural environment. While noise pollution is less frequently cited, it is a significant concern, particularly in urban areas. Consequently, it would be advantageous to prioritize the implementation of pollution reduction initiatives in these areas, particularly with regard to waste management, machinery emissions, and water purification. As [8] has also emphasized, the construction sector is responsible for 23% of air pollution, 40% of drinking water pollution, and 50% of landfill waste. Consequently, it is imperative to take into account the environmental implications of construction activities, as each action has a substantial effect on the surrounding environment. A substantial body of research has identified that individuals residing in close proximity to construction sites and construction workers are susceptible to developing ocular irritation, asthma, bronchitis, pulmonary impairment, cancer, heavy metal poisoning, and cardiovascular effects that can potentially lead to premature mortality [7]. In response to the second inquiry, 12.41% of respondents identified additional categories of pollution stemming from construction sites,

including deforestation, erosion and landslides, noise, water and air pollution, pollution from workers bringing food to the site, and unfit toilets.

4.5. Main factors contributing to environmental pollutions on construction sites

The following section will illustrate the main factors influencing environmental pollutions on construction sites.

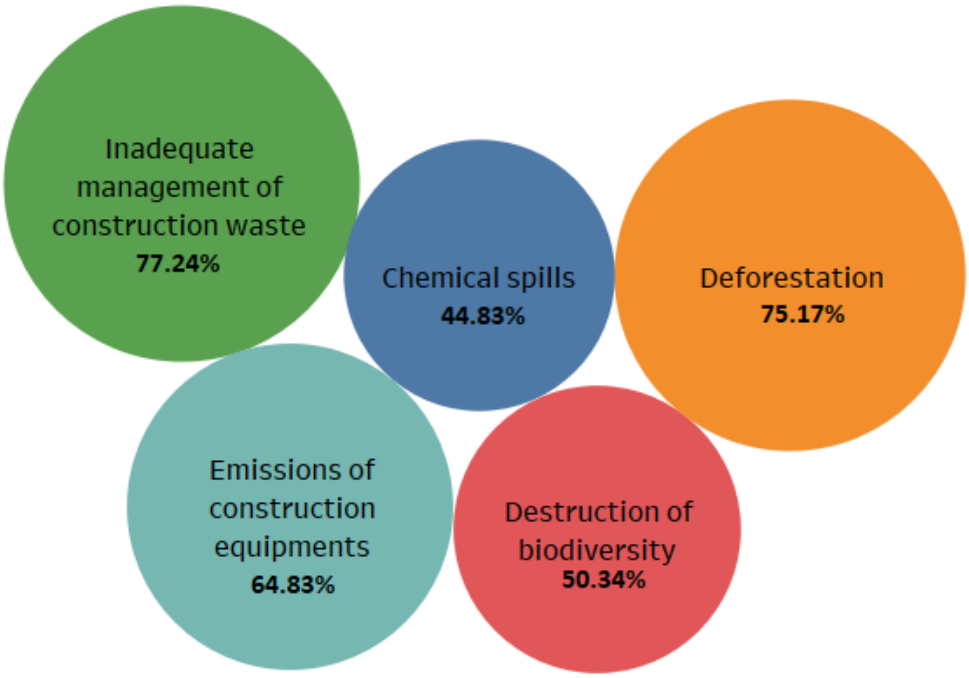

Figure 4 : Factors contributing to environmental pollutions on construction sites

As demonstrated in Figure 4, the inadequate management of construction waste is regarded as the predominant factor contributing to pollution, underscoring the importance of implementing collection systems on building sites. However, Figure 4 also indicates that approximately 46.9% of respondents lack skips on site to effectively manage construction waste, underscoring the necessity to enhance awareness of the availability of skips on construction sites. Furthermore, concerns have been raised regarding the impact of construction practices on deforestation and the destruction of biodiversity, indicating that such activities can have long-term detrimental effects on ecosystems. As [7] observes, the impact of a construction project is pervasive and evident in all its aspects. However, if we consider the initial damage caused by construction, it is clear that deforestation is a primary concern. The process of clearing a site for construction inevitably disrupts the environmental balance of the area.

4.6. Construction sites' environmental pollutions and their impact on human health

The vast majority of respondents (96.6%) acknowledge the various ramifications that environmental pollutions stemming from construction sites exert on human health. This observation mirrors a pervasive cognizance of the peril engendered by such forms of pollution, particularly in the guise of dust, chemicals, and exhaust fumes. However, it is noteworthy that five respondents expressed uncertainty regarding the impact of such pollutions on human health, potentially due to a lack of information concerning the indirect effects and long-term consequences of these pollutants. Research has demonstrated that mortality resulting from the inhalation of polluted air occurs annually in the USA. The magnitude of this mortality is substantial, with estimates ranging from 22,000 to 52,000 deaths annually, with a preponderance among construction workers. A study conducted in Great Britain revealed that approximately 500 construction workers succumb to lung cancer annually [54]. Additionally,[51] acknowledged that excessive noise pollution can contribute to elevated blood pressure and hearing impairment in individuals residing in proximity to construction sites. The pollution caused by construction and demolition activities can have long-term effects on the health of workers. This pollution's harmful effects extend beyond the immediate vicinity of construction sites, as it is capable of being transported by wind, thereby adversely impacting the air quality of surrounding areas.

The figure 5 illustrates the extent to which construction sites' environmental pollutions affect human health.

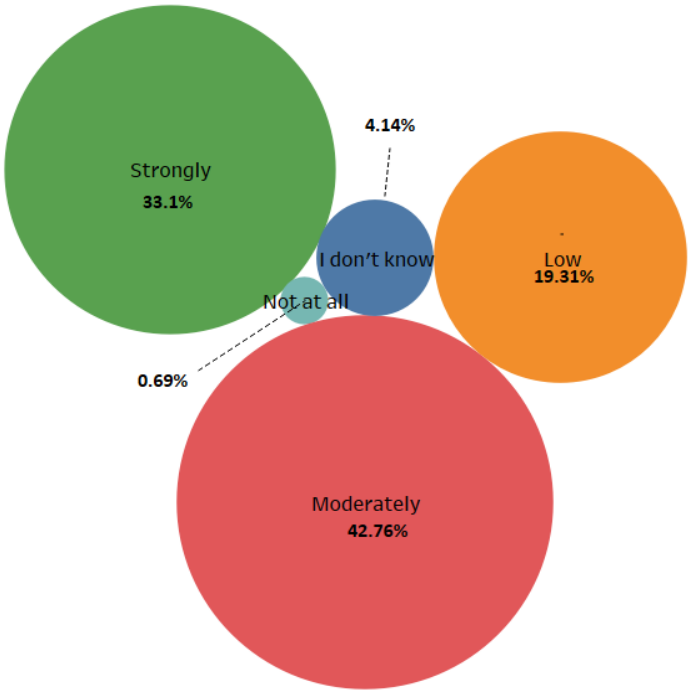

Figure 5: Extent of the impact of construction sites' pollution on human health

As illustrated in Figure 5, the majority of respondents perceived pollution to have a moderate (42.76%) or strong (33.10%) impact on health, thereby underscoring the perceived severity of health issues associated with worksite pollution. A proportion of respondents (19.31%) consider the impact to be low, perhaps because they have not observed any immediate or direct health effects. This observation may also highlight variations in the perception of environmental impact, which is known to be subjective and influenced by individual experiences or proximity to construction sites. However, studies have demonstrated that individuals residing in close proximity to construction sites and construction workers are prone to developing ocular irritation, asthma, bronchitis, lung damage, cancer, heavy metal poisoning, and cardiovascular effects that can lead to premature mortality [7].

4.7. Consideration of construction's environmental pollution by sector professionals

The prevailing opinion among industry professionals (84.14%) is that environmental pollution from construction sites is an "extremely serious problem." This perception has the potential to catalyze modifications in construction practices and the adoption of more stringent measures to curtail environmental impacts. This collective recognition underscores the pressing nature of the issue, emphasizing the need for prompt action to mitigate environmental and health consequences.

Indeed, by leveraging the recommendations proposed by respondents to enhance the management of environmental pollution on worksites, it is possible to achieve substantial improvements in the management of environmental pollution, thereby contributing to sustainable development in the construction sector. In addition, respondents X proposed a series of recommendations, including the implementation of metal scaffolding, the establishment of legislation governing the operation of construction sites in a manner that preserves the environment, the organization of workshops aimed at raising awareness about pollution in construction sites, the utilization of environmentally-friendly building materials, and the provision of waste receptacles on construction sites to facilitate waste collection. Notably, the majority of respondents underscored the paramount importance of reducing pollution, signifying substantial public support for ecological initiatives in Bujumbura.

4.8. Proposed mitigation measures

The surveyed respondents put forth a series of mitigation measures aimed at reducing environmental pollution stemming from construction projects.

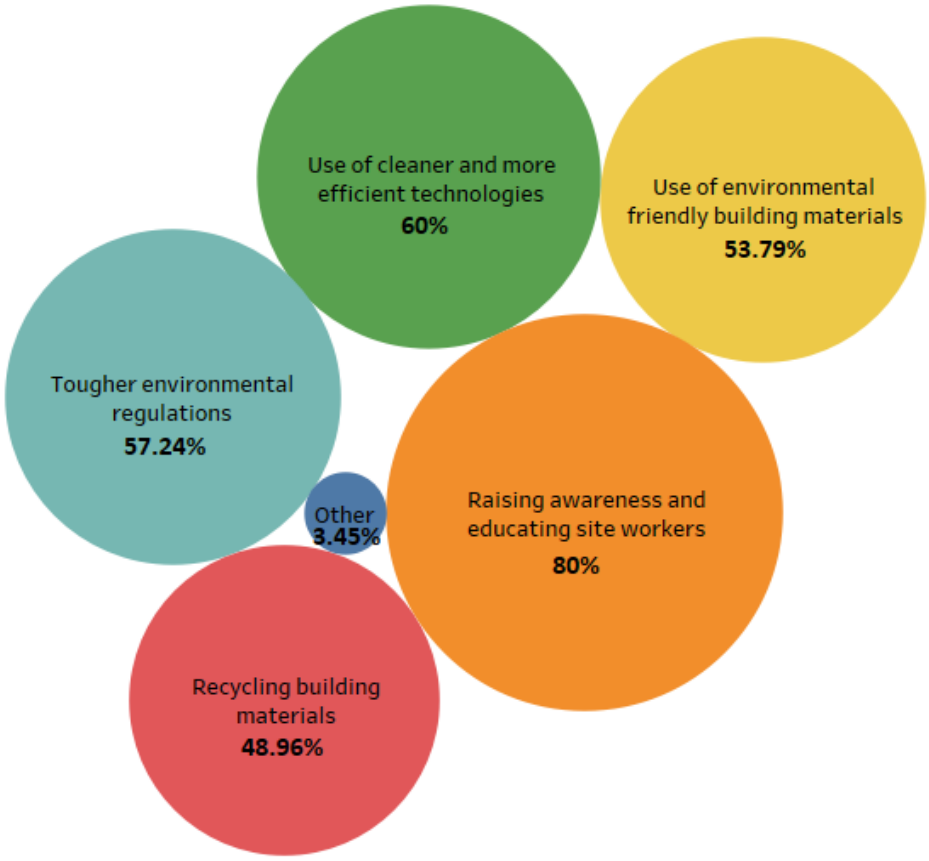

Figure 6: Mitigation measures to reduce construction sites' environmental pollution

As demonstrated in Figure 6, the majority of respondents advocate for the implementation of practical and educational measures, such as worker awareness, which is perceived as a priority. This is followed by the adoption of greener technologies and the strengthening of regulations. These responses suggest that, in addition to technological solutions, the promotion of education and worker engagement are perceived as pivotal to the reduction of pollution. This finding underscores the necessity for more stringent public policies within the construction sector. [55] advances the notion that the fundamental criteria for co-construction encompass enhanced worksite management, the utilization of eco-friendly building materials, harmonious integration of buildings into the ecosystem, and related factors.

However, respondents X proposed a series of measures aimed at curbing the environmental degradation associated with construction activities. These measures include the establishment of distinct zones for building and non-building operations, the aggregation of waste materials at each stage of the construction process, the implementation of an environmental impact assessment prior to the initiation of any construction project, and the

integration of environmental management courses within Burundi's educational curriculum, with a particular emphasis on construction and architectural disciplines. This finding aligns with the results of studies conducted in Burundi on the role of higher education in promoting green practices in the construction sector [21]. It is evident that the enhancement of worker awareness and the adoption of cleaner technologies are regarded as pivotal levers for the realization of a greener worksite. This underscores the imperative for enhanced training of personnel within the sector and the promotion of innovative technical solutions.

5. CONCLUSION AND RECOMMANDATIONS

The findings indicate a notable enhancement in awareness and interest concerning the environmental concerns associated with construction sites. However, there are still deficiencies in current practices, particularly with regard to waste management. To address these issues, it is imperative to enhance public awareness, thereby promoting the adoption of more sustainable practices in this sector. Education on sustainable practices is also required. These findings establish a foundation upon which the Burundian government can develop educational and regulatory initiatives aimed at reducing the environmental impact of the construction sector while protecting public health and supporting sustainable development. The strategic recommendations outlined in this study are designed to enhance construction site management practices and mitigate environmental pollution. These recommendations include the implementation of awareness-raising and educational programs targeting construction workers and the general public, the promotion of environmentally-friendly building materials, and the establishment of a system for continuous monitoring and evaluation of environmental practices on construction sites. A key recommendation was the involvement of local communities in the decision-making process concerning construction projects. The study was constrained by significant limitations, primarily due to the unavailability of equipment for on-site measurement of acoustic discomfort, water and air pollution, and the paucity of publications and research conducted in Burundi on related subjects. To enhance the rigor of future studies, it is advised that fieldwork be conducted with the requisite equipment to gain deeper insights into the diverse forms of pollution generated by construction sites. This approach should be complemented by a more comprehensive strategy, encompassing technical assessments of pollution and the perspectives of other stakeholders directly affected by the environmental consequences of construction sites.

6. AUTHORS' CONTRIBUTIONS

Seth Mbonimpa was responsible for the collection of data and the composition of the initial draft of the paper. Legrand Cirimwami, Jean Claude Ngenzi, Daniel Hatungimana, and Samuel Rudahinyuka provided guidance, revision, and feedback, and they also edited the paper so that the current version was obtained.

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