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The Cost of Plastic Pollution in N'Djamena: A Case Study

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Abstract

Plastic pollution is a major problem: it damages health, reduces ecosystem services, and affects local economies. Despite its importance, available valuation efforts have focused primarily on the damages caused by plastic in marine environments. Far less is known about the effects of plastic waste in inland settings. This paper addresses this gap by estimating in monetary terms the damages caused by the inappropriate disposal of plastic waste in an inland context. The study area is located along a canal that crosses N'Djamena, the capital of Chad. Using data from a primary survey and applying standard valuation techniques, the paper estimates the social cost of plastic pollution at over USD3000 per ton in 2020. In addition, it shows that the impacts of plastic waste vary significantly across the study area: households residing within 20 meters of the canal bear more than 75 percent of the total damages. The paper identifies the main valuation challenges and proposes recommendations to reduce plastic waste damages.

Keywords

Solid Waste, Plastic Pollution, Economic Cost

1. Introduction

Plastic pollution is a major global challenge. Currently, an estimated 30 million tons of plastic waste lie in seas and oceans, and a further 109 million tons have accumulated in rivers [1]. Other quantities are found in terrestrial environments such as urban areas, landfills, and agricultural land. Plastics' inherent resistance to biodegradation[1] leads to their growing build-up in the environment [2]. The accumulated plastic waste generates significant negative impacts on ecosystems, the economy, and people's health. A recent study estimated the minimum lifetime cost of the plastic waste produced in 2019 at about USD3.7 trillion – more than India's gross domestic product [3]. Moreover, the COVID-19 crisis led to a rise in littering, food takeaway packaging, and plastic medical equipment, such as masks[2].

The problem of plastic pollution is at the forefront of the environmental agendas of many governments and international organizations, such as the World Bank and the United Nations Environment Programme (UNEP). To date, most efforts to understand the magnitude of damages caused by plastic have focused on marine environments. Studies have estimated the economic damages due to marine plastic pollution at different levels: global level, e.g. [3] [4]; regional level, e.g. [5] [6] [7]; the coastal areas of individual countries, such as the United Kingdom [8], Norway [9], the Galapagos Islands [10], Indonesia [11]; and specific economic sectors, such as fisheries in Thailand [12] and tourism in South Africa [13].

Far less is known about the effects of plastic waste in inland environments. Although the presence of plastics has been documented at specific terrestrial sites, e.g., home gardens, urban agglomerations, and agricultural land [14] [15] [16] [17], there has been little analysis of the type and extent of impacts caused by plastic waste in such areas. This paper contributes to addressing this gap by estimating the economic damages caused by the inappropriate disposal of plastic waste in an urban area of a developing country—N'Djamena, the capital of Chad. The valuation is particularly important, given the serious problem of plastic waste management faced by the city: in 2010, N'Djamena banned the import, marketing, and use of plastic bags[3]. While this reduced plastic pollution for a short time – only during the mandate of the city's mayor at the time - the trend has reversed in recent years, with increasing amounts of plastic waste blocking waterways and damaging the environment[4].

To the authors' knowledge, this is the **first study** that estimated in monetary terms the damages caused by plastic pollution in an inland setting. It is based on the data collected in the context of the World Bank's Country Environmental Analysis for Chad [18].

2. Study Area

The study area is located along the *Canal des Jardiniers*, which crosses the city center from the south to the north. The canal is primarily used for rainwater drainage. The study area stretches along the canal and covers about 25 ha (**Map 1**, red contour). It is home to 380 households, which include about 3540 resi-

[1]Recently, bioplastics have been touted as the solution to plastic pollution, however, even these materials fail to biodegrade unless subject to certain controlled conditions [19].

[2]https://www.oecd.org/environment/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.htm

[3]The Order No. 007/MCPI/SE/DG/DCT/93 of May 22, 1993, prohibited the import of non-biodegradable plastic packaging throughout the territory. It was implemented by the mayor of the city of N'Djamena in 2010.

[4]https://atrenviro.pro/publications/actualites/proliferation-plastiques-ville-de-ndjamena/

dents. It covers a mix of residential and commercial buildings, with shops and markets. Most structures are mud houses (*maisons en terre battue*). Its socio-economic characteristics (income levels, poverty rate, education levels, etc.) are believed to reflect the city's average (**Table 1**). However, the household size is slightly larger in the study area than the average of N'Djamena (9 vs. 6).

There are no formal waste collection or transfer centers in the vicinity of the canal. Therefore, the waste originating from this area and other upstream areas is usually dumped into the canal. The canal is cleaned every few years, but in the intervening years, waste accumulates rapidly in the canal; a large proportion of this waste consists of plastics. Local authorities estimated that the portion of the canal located in the study area held about 300 tons of solid waste in 2020, a third of which consisted of plastic waste, such as bottles, bags, and other packaging.

Map 1. Study area. Source: Authors, based on Google Earth and GPS coordinates of the study area.

Table 1. Socio-economic characteristics of N'Djamena.

	Unit	N'Djamena
Population (2021)	million people	1.5
Household size (2018)	people/household	6
Literacy rate (2018)	% of total population	76
School enrollment rate (2018)	% of total population within 6 - 11 years old	69
Annual income (2018)	USD/person	3000
Subjective* poverty rate	% of total population	17

Sources: Population from [20]; remaining data from [21]. Note: * Based on the households' own perception of their poverty level [21].

The waste obstructs many sections of the canal and contributes to several negative externalities: 1) health impacts, such as malaria, due to bites of mosquitoes that reproduce in the stagnant water created by the clogged canal; diarrhea and dysentery due to contamination of household water by polluted water from the canal[5]; 2) reduction in house value due to bad odor and aesthetic nuisance; 3) flood damages during rainy years, such as 2020, when torrential rains caused the flooding of a significant area around the canal.

3. Approach

Valuation techniques. A wide range of valuation techniques has been developed in environmental literature to estimate damages to natural resources [22] [23] [24]. Environmental damages can be valued either through exchange value-based approaches (i.e., techniques based on observed or imputed prices, replacement costs, treatment costs) or welfare-based approaches (i.e., techniques that seek the willingness to pay for a good, or to accept compensation for a loss) [25] [26]. Estimating different types of damages via comparable measures of value is essential to obtaining meaningful results. In this paper, we use exchange value-based approaches to estimate the damages caused by the solid waste accumulated in the canal, due to the lack of information related to welfare-based measures:

- Health impacts. The costs related to the morbidity associated with malaria, diarrhea, and dysentery are estimated based on the actual treatment costs, costs of caring for sick children, and income losses among sick adults.
- House devaluation. This loss is estimated based on hedonic prices, through the difference between the average value of houses located in close proximity to the canal and that of very similar houses located further away.
- Flood damages. These are estimated based on the actual repair cost of houses, income losses to businesses during the flood days, and other costs related to the temporary transfer of certain households.

Data collection. A primary survey was conducted among all 380 households of the study area. It was carried out through personal interviews based on a structured questionnaire. Due to time and resource constraints, the survey did not seek to collect a comprehensive range of data; rather, it focused on the essential information needed for the economic valuation: a few household characteristics (e.g., income, distance from the canal), types of solid waste in the canal (e.g., plastics, household waste), diseases (frequency, costs), flood impacts (types of damages, costs of repair) and households' perceptions regarding the contribution of waste disposal to the damages incurred. Moreover, to improve the understanding of the overall situation, personal interviews were also conducted with local authorities (*chefs de carré*) to collect information related to the overall surface affected by floods, flood frequency, and house prices in different locations of the study area.

[5]The residents receive water from boreholes, open wells, and public water supplies. Contamination can occur either through runoff of surface water into open pits, or through infiltration of polluted water into groundwater. The first type of contamination occurs largely due to canal obstruction by solid waste.

Data analysis. The data collected through the survey were analyzed for the entire study area. However, plastic pollution affects households differently, depending on their distance to the canal, construction material, livelihoods, etc. Because of these differences, the study area has been divided into three zones, based on their distance from the canal (Table 2).

Table 2. Characteristics of the three zones in the study area.

Zone	Distance to the canal	Surface (ha)	Number of households
A	0 - 20 m	5.6	107
B	20 - 50 m	8.4	163
C	>50 m	11.2	110
Study area	**Total**	**25.2**	**380**

Source: Household survey.

4. The Economic Cost of Plastic Waste

This section describes the valuation of the three types of damages due to inappropriate disposal of solid waste in the study area (Sections 4.1-4.3), based on the approaches mentioned previously. It then estimates the damages due to plastic waste for the study area and for the three zones (Section 4.4). All the estimates refer to the year 2020.

4.1. Health Impacts

The survey results indicated 3100 disease cases (episodes) during July-August 2020, of which malaria accounted for about 60 percent (Table 3). In addition, the residents located in close proximity to the canal (zone A) stated that they were affected by these diseases to a similar extent throughout the rest of the year. Hence, assuming a disease prevalence similar to that of July-August (8 cases/household every two months), we obtain that the households residing in zone A suffered from 4300 cases of illness during the rest of the year. Overall, Table 3 indicates a total of 7400 cases of malaria, diarrhea, and dysentery in 2020.

Table 3. Number of disease cases in the study area (2020).

Type of disease	Number of cases during July-August [a]	Number of cases during the rest of the year[b]	Total number of cases[c]	Estimated cases due to canal obstruction[d]
Malaria	1800	2600	4400	4100
Simple diarrhea	800	1100	1900	1800
Dysentery	500	600	1100	1000
Total	**3100**	**4300**	**7400**	**6900**

Sources: [a] household survey responses; [b] estimated based on the average number of cases by household (8 cases per household every 2 months), the number of households living close to the canal (107), and the duration of the rest of the year (10 months); [c] = a + b; [d] Estimated by multiplying the cases obtained at point c with the difference between the prevalence of each disease in the study area and that at the national level. All the estimates are rounded to the nearest hundred.

The respondents suggested that most cases were due to the obstruction of the canal by solid waste; they argued that during previous years when cleanup efforts were conducted, the occurrence of these diseases was very rare. However, the proportion of cases attributable due to canal obstruction is not known. In the absence of this information[6], we estimate it through the difference in the prevalence of these diseases in the study area compared to the national level [27]. Accordingly, the total number of cases due to canal obstruction is estimated at roughly 6900. The cost related to these diseases covers the components below:

⇒ *Treatment cost*. Illness can be treated either through self-medication (at home), or in healthcare centers. The respondents indicated that they used self-medication primarily, because it is cheaper than the alternative. The average cost of treatment through self-medication is about USD6/case of malaria, USD2/case of simple diarrhea, and USD3/case of dysentery. Based on these estimates and the number of cases due to canal obstruction reported in **Table 3**, the total cost of treatment is estimated at about USD32,000.

⇒ *Cost of caring for sick children.* In addition to the cost of treatment, illnesses impose costs on adults, notably in terms of lost wages due to having to stay home to care for sick children. The proportion of children under five in the total number of cases is not available in the study area. However, the IHME (2020) statistics for Chad indicate that children under five account for about 22 percent of total malaria cases and 38 percent of diarrheal cases. Applying these percentages to the study area[7], we obtain 920 cases of malaria, 670 cases of simple diarrhea, and 410 cases of dysentery among children. Considering the average number of days of each disease[8], it is estimated that 17,800 days have been spent to caring for sick children. Based on the average daily wage of USD8.4/day[9], the loss of income due to caring for small children reaches about USD150,000.

⇒ *Loss of income among sick adults*. The suffering and discomfort associated with severe illnesses can render adults unable to work, leading to loss of income during illness. [27] statistics indicate that in Chad, adults of working age (25 - 65 years old) account for about 21 percent of total malaria cases, and 28 percent of diarrheal disease cases. On this basis, about 1200 severe cases among adults were estimated: 900 of malaria and 300 of dysentery[10]. Considering the average dura-

[6]In theory, comparing the disease prevalence in the study area with that in similar urban areas but subject to appropriate solid waste disposal, would have provided more accurate results. However, data on malaria prevalence in urban areas is not available in the country's most recent Demographic and Health Survey [28]; in addition, the same source provides the diarrheal prevalence in urban areas only for children under five years old. Since these data are both partial and old (2014), we preferred to use more updated estimates, based on the IHME [27]. However, these estimates are only available at the national level.

[7]There is no information on the proportion related to simple diarrhea and dysentery. As both illnesses are part of the diarrheal diseases, we apply the same percentage (38 percent of the total) to obtain the number of under five cases of simple diarrhea and of dysentery.

[8]Based on local interviews, these are about 14 days for malaria, 3 days for simple diarrhea, and 7 days for dysentery.

[9]Estimated based on the data provided by [21].

[10]Simple diarrhea was not considered a severe illness.

tion of each disease[11], we obtain a total of 14,400 days with the inability to work. Using the daily wage reported above (USD8.4/day), the loss of income among adults of working age is estimated at about USD121,000.

Adding up the three estimates obtained above, the cost related to the health impacts of solid waste is valued at USD303,000 (a).

4.2. House Devaluation

The inappropriate disposal of solid waste has also led to the depreciation of the value of the houses located in the proximity of the canal. We estimate this impact based on hedonic prices by comparing the average price of houses facing the canal with that of the houses right behind them. The survey responses revealed that:

⇒ The average price of houses directly facing the canal (zone A) is about USD27,100;

⇒ The average price of houses located further away from the canal (zones B and C) is about USD49,600;

⇒ The houses located in the two groups are very similar in terms of materials, types of construction, and size.

Knowing that 107 houses are directly facing the canal, the impact of inappropriate disposal of solid waste is estimated at about USD2.4 million. The average lifespan of a mud house in this zone is about 10 years. Using a discount rate of 6 percent[12], the annual value of the solid waste impact on house devaluation is estimated at about USD328,000 (b).

4.3. Flood Damages

In addition to the losses mentioned above, the obstruction of the canal by solid waste contributed to water overflowing and flooding a vast area around the canal during the torrential rains of August 2020. This led to several damages, all of which were estimated based on the information provided by the respondents:

⇒ Direct damage to houses, resulting in repair costs. **Figure 1** shows the average reported costs in the three zones (*i.e.*, mean and median values). In each zone, they vary widely, with many houses experiencing relatively low repair costs, and some suffering very high costs. It is interesting to note that the average costs decline with increasing distance from the canal[13]. Overall, based on the respondents' answers, the total repair costs attained USD84,000.

⇒ Direct loss of income from economic activities (e.g., shops, street vending) which shut down during flood days, amounting to about USD10,000;

⇒ Other forgone income by households forced to move temporarily away from the area while their homes were repaired, estimated at[14] USD182,000.

[11]Based on local interviews, this is about 14 days for malaria, 3 days for simple diarrhea, and 7 days for dysentery.

[12]Based on the guidelines provided by [29].

[13]For example, the figure shows that the mean cost declined from USD443/house in zone A, to USD324/house in zone B, to USD191/house in zone C.

[14]Estimated as 180 households * 2 months * USD253/person/month * 2 adults/family.

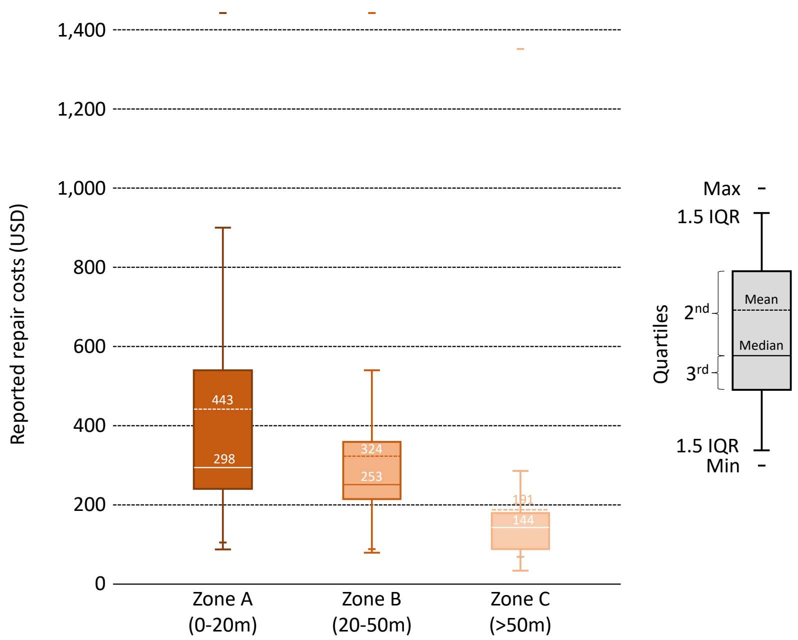

Figure 1. Distribution of the repair costs across the selected zones. Source: household survey answers.

Adding up the above estimates, the flood damages in the study area[15] are estimated at USD276,000 (c).

4.4. Total Cost Due to Plastic Waste

Based on the above valuations (a, b, c), the total cost related to the obstruction of the canal by the solid waste in the study area is estimated at about USD907,000 in 2020. As plastic waste represents about a third of the amount of solid waste clogging the canal[16], the associated damage in the study area is roughly estimated at about USD302,300. Overall, the economic cost corresponds to **more than USD3000/ton of plastic waste** in 2020 - substantially higher than the average impact of solid waste estimated for N'Djamena at USD60/ton per year [18].

Spatial distribution of the overall damages is presented in Table 4. It shows that **zone A is the most affected, accounting for more than 75 percent of the total plastic damages**. The proximity to the obstructed canal explains the high occurrence of disease, the large decline in house values, and the severe flood damages. The much lower damages in zones B and C indicate that damages decline with increasing distance from the canal; in fact, no effects on house devaluation were reported by the residents living in the zones further away from the canal.

[15]In addition, these floods caused damages beyond the study area, on an additional 31 ha. The houses in this area suffered from low damages, due to the relatively large distance between the canal and the houses. Interviews with local authorities revealed that floods affected 322 houses, and the average repair cost was about USD174/house. Accordingly, the economic damages in this area was estimated at about USD56,000. However, as they occurred outside the study area, they are not included in this analysis.

[16]100 tons of plastic waste out of a total of 300 tons of solid waste, see Section 2.

Table 4. Summary of the total estimated damages due to plastic waste, by zone (2020).

	Zone A	Zone B	Zone C	Study area
Health impacts (USD)	71,800	17,600	11,600	101,000
House devaluation (USD)	109,300	0	0	109,300
Flood damages (USD)	47,600	38,400	6000	92,000
Total (USD)	**228,700**	**56,000**	**17,600**	**302,300**
Total (% of total damages)	76%	18%	6%	100%

Source: Sections 4.1-4.3 for the overall estimates and household survey for the disaggregation across the areas.

As the three zones vary in terms of area and number of households (Table 2), it is interesting to examine how the damages affect each of them. In this light, Figure 2 shows the damages per household due to plastic waste. For the whole study area, this damage averages to USD800/household—more than ten times the damage per household due to municipal solid waste estimated for the entire city by [18]. Moreover, the households located in zone A suffer the most: their average damage is more than seven times higher than that inflicted on the zones located further away (about USD2100 in zone A vs. USD200 - 300 in zones B and C, see Figure 2).

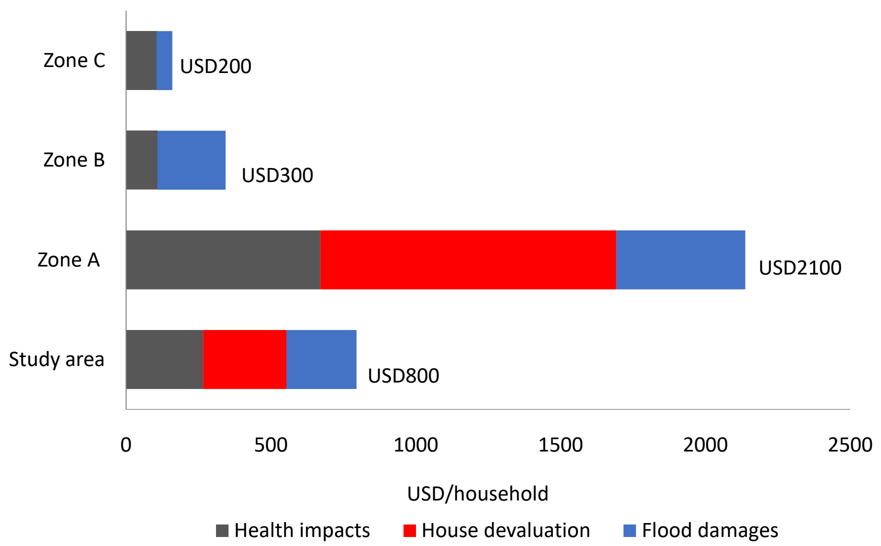

Figure 2. Damages per household due to plastic waste, by zone (2020). Source: Sections 4.1-4.3 for the overall estimates and household survey for the disaggregation across the areas. The estimates are rounded to the nearest hundred.

Figure 3 illustrates the per hectare damages due to plastic waste. As above, zone A stands out with the highest damage, estimated at USD40,800/ha. This is more than six times bigger than that incurred by the other zones. Once again, the close proximity to the obstructed canal explains the high magnitude of the damages in each category for zone A.

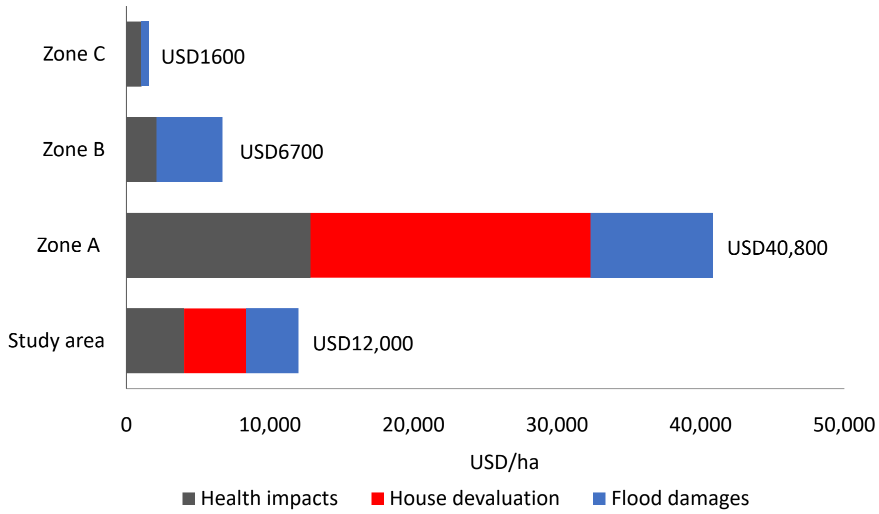

Figure 3. Per hectare damages due to plastic waste, by zone (2020). Source: Sections 4.1-4.3 for the overall estimates and household survey for the disaggregation across the areas. The estimates are rounded to the nearest hundred.

5. Valuation Challenges

Although the study benefitted from valuable primary information, it is important to note that the valuation was subject to several limitations, mostly related to attribution challenges:

⇒ *The contribution of solid waste to the burden of disease*. Ideally, a comparison between the prevalence of disease in the study area and that in an identical area, but subject to appropriate solid waste disposal would have been useful for the valuation. In its absence, we used as a proxy the difference between the prevalence of each disease locally and nationally. This may understate the difference because the national average also includes areas with poor waste management.

⇒ *The contribution of solid waste to flood damages*. Sufficiently intense rain can cause flooding even if the canal is clear, but any obstruction in the canal will increase the likelihood and severity of flooding. It is not known how much the likelihood and severity of flooding increases as a result of obstructions, and whether the composition of that obstruction (e.g., the share of plastics, shape) affects it.

⇒ *The contribution of plastic waste to total damages*. Plastics encompass a large range of materials (e.g., polyethylene, polyamides, etc.) and sizes (e.g., macro-plastics, micro-plastics, nano-plastics) which may contribute differently to economic damages. For example, macro-plastics might be more likely to obstruct the canal because they bind materials together, while micro-plastics, if ingested, are believed to cause other problems such as exposure to contaminants, internal injuries, or reduced nutrition [2]. In the absence of cause and effect relationships between the different types of plastics and their possible effects, this paper focuses only on macro-plastics, and estimates their contribution to the total damage based on their proportion in the total volume of solid waste dumped in the canal.

These considerations suggest that the study's results underestimate several damages, by not capturing the cost related to the potential ingestion of micro-plastics, injuries due to floods, carbon emissions, etc. At the same time, they might overestimate certain effects, by failing to exclude factors other than solid waste which could potentially contribute to flooding damages; however, the degree of overestimation is believed to be low. Due to the above limitations, the results should be regarded as **orders of magnitude** of the impacts of plastic waste in the study area. In addition, as the results represent first-time estimates of damages in a specific context (urban inland environment in a Sahelian country during a rainy year), they should not be generalized to areas characterized by different conditions.

6. Conclusions

This paper demonstrated that plastic pollution could have a large economic impact on Chad's urban areas. **Key messages** include:

⇒ Damages due to plastic pollution reach over USD3000/ton in the study area in 2020. The lack of studies conducted in other inland environments makes it impossible to compare these results with plastic damages in other areas[17]. However, the estimated damage is substantially higher than the average impact of solid waste estimated for N'Djamena at USD60/ton per year by a different study [18].

⇒ The most affected zone is located within 20 meters of the canal and bears more than 75 percent of the total plastic damage. The close proximity to the obstructed canal is the major reason for the decline in house values, the high occurrence of disease, and the intense flood damages in this zone.

⇒ There are large differences in damages across the three zones. The average damage per household in zone A is more than seven times higher than that inflicted on the zones located further away[18]; similarly, the damage per hectare in zone A is more than six times higher than those in the other two zones[19].

These results point out to several **priority areas** for future work in N'Djamena and other urban areas:

⇒ identify hotspot areas of solid waste (including plastic), determine possible actions to reduce the damage (e.g., clean-up, recycling, reuse), and carry out cost-benefit analyses to identify the most socially attractive solutions to reduce damages.

⇒ strengthen the collection of plastic waste data (e.g., systematic assessment of quantities generated and disposed of in areas of interest) and health informa-

[17]As previously mentioned, most valuation studies to date focused on marine plastic, which generates impacts (*i.e.* loss of fishing and aquaculture, tourism value, marine biodiversity) that are very different than those estimated in this study (*i.e.* disease, house depreciation, flood damages), hence the results are not comparable across studies.

[18]*i.e.* USD2100/household in zone A, USD300/household in zone B, and USD200/household in zone C.

[19]*i.e.* USD40,800/ha in zone A, USD6700/ha in zone B, and USD1600/ha in zone C.

tion (e.g., prevalence of different diseases at the city level), and deepen the knowledge of the cause-and-effect relationships between the exposure to different types of plastic and possible health outcomes.

⇒ identify practical ways to reinforce the municipal decree prohibiting the use of plastic bags; support waste recycling and promote the reuse of recycled products, e.g., by supporting partnerships between the *Société Tchadienne d'Industrie et de Plastique*, which is currently the only plastic recycling firm in Chad, and agencies such as the International Finance Corporation (IFC); invest in more solid waste collection points and sanitary landfills [18].

⇒ conduct new studies to estimate the damages due to plastic waste in inland urban environments. Their results should provide damage estimates for a wider range of contexts, which will further improve the understanding of the range of possible costs and how they vary according to local conditions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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