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Computer Aided Assessment of Impact of Plastic Waste During COVID-19 Pandemic in Urban Areas of Developing Countries

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Management of plastic waste during sanitary emergencies requires the development of computational tools to estimate its environmental impact. The purpose of this work is to develop a simulation model to predict the plastic waste trends during sanitary emergencies, such as the COVID-19 pandemic, in urban regions of developing countries. The proposed simulation consists of two models: a municipal waste generation model and a sanitary emergency (COVID-19) dynamics prediction model. The plastic waste generation is estimated based on the population growth rate and the per capita waste generation rate, which in the model is increased for the infected population. In the second component, a Gated recurrent unit (GRU) recurrent neural network, trained with historical COVID-19 data from a specific urban region in Colombia, is used to simulate/predict the behaviour of a sanitary emergency such as an epidemic in that specific region. Recurrent neural networks have demonstrated to be a convenient tool for predicting the dynamics of a transmissible disease such as COVID-19. The GRU output is integrated into the simulation models of plastic waste generation. For the evaluation of the model, the total waste, and plastic waste generated for the last three months of 2021 in the Bucaramanga Metropolitan Area were estimated. The results show a slight increase (10 %) in plastic waste generation for the epidemic scenario that resembles the actual data. For the three months is the evaluation time interval, the ground truth average plastic waste generation per month was 9.03 t. The model forecast had a mean absolute error of 0.62 t for the three months in the evaluation time interval.

1. Introduction

The COVID-19 pandemic has deepened the plastic waste management problem. This has happened due to the increased use of plastic in personal protective equipment and single-use plastics, to prevent the spread of the virus, as well as for the sale of vegetables and food packaged in plastic, among others (Klemeš et al., 2020). As a result, waste generation has increased compared to that observed under "normal" conditions because the population has been forced to use these products to limit the virus transmission. Consequently, in April 2020 the residential waste in the United States reached a peak of 20 % to 30 % higher than normal (Kulkarni et al., 2020). Also, according to press releases on 11 March 2020, the generation of medical waste increased (+370 %) in Hubei, China, with a high proportion of plastics. Moreover, the municipal solid waste decreased by 30 % in large and medium cities (Klemeš et al., 2020).
In particular, Colombia has become the fourth largest producer of plastic waste in Latin America, with an annual volume of plastic consumption of 500,000 t. 27 % of these plastics correspond to single-use plastics such as packaging, packing, PETs, etc (Brooks et al., 2020). Figure 1a shows an increase of 132 % in the amount (t) of plastic collected by 561 recycling service providers distributed in 27 departments of Colombia. For 2019, plastic had a report of around 209,415 collected tons, and for 2020 it was reported a total of around 486,231 collected tons (Superintendencia de servicios públicos domiciliarios, 2021). Figure 1b shows a noticeable increment in the collected plastics waste of 275,815 t from January to December 2020. The highest reported

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increase of average t of plastic waste was observed in July with a reported average waste of 22,034 t, in August it was reported a total of 23,169 t, while in September 31,359 t were reported. More specifically, Santander (department of Colombia, whose capital is Bucaramanga, our main case study) reported that of all the type of materials composing total waste, plastic is the second most prevalent, with a percentage of 29.72 % (Superintendencia de servicios públicos domiciliarios, 2021).

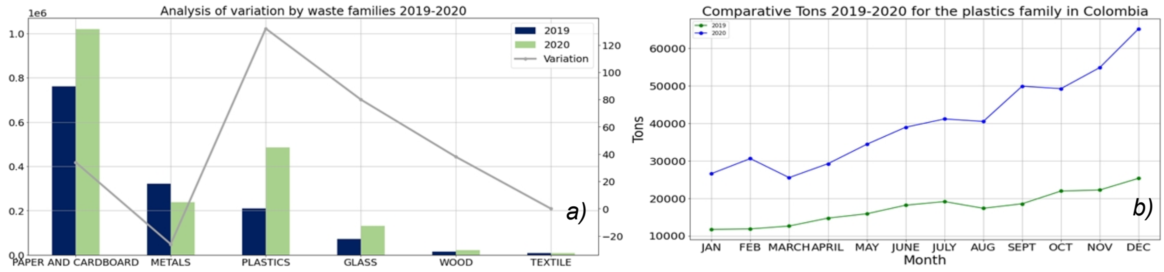

Figure 1: a) Variation by type of waste material collected in 2019 & 2020; b) Comparison of 2019 vs 2020 collected plastic waste (t) in Colombia (Superintendencia de servicios públicos domiciliarios, 2021).

Several simulation models for the generation of medical and plastic waste during the pandemic have been explored. For instance, Yu et al. (2020) proposed to use a reverse logistics network to optimize decisions about establishing temporary waste treatment facilities and transportation strategies during the pandemic. Hence, the capacity to manage the medical waste in a short period of time is strengthened, and the risk of contagion from the collection, treatment of medical waste and biohazards is reduced (Yu et al., 2020). On a related work by Chowdhury et al. (2022), the medical waste generated for the initial period of the health emergency from March 2020 to May 2021 was estimated. This estimate assumes that the infected, ICU, deceased, isolated and quarantined population are the main source of medical waste. This assumption is reinforced by their results, which show that an 80 % increase in the generation of medical waste after the pandemic started (Chowdhury et al., 2022). Although both studies presented detailed simulation models, their scope is limited to the management of healthcare waste generation in clinical facilities. To the best of the authors' knowledge, estimation of other types of waste, such as plastics, in urban regions during broad sanitary emergencies has not been modelled in the literature.

In this work, we developed a simulation model that integrates information of COVID-19 dynamics and per capita waste generation information to estimate the amount of plastic waste on an urban region. This simulation serves as an example of the potential application of this type of model to ongoing sanitary emergencies. The presented model allows for estimation of the trends of plastic waste generation during sanitary emergencies. This information might inform authorities in the decision process for mitigating plastic waste environmental impact.

2. Methods

This section describes the simulation model implemented in the paper. The proposed simulation consists of two components: a municipal waste generation model and a sanitary emergency (COVID-19) dynamics prediction model (Fig. 2). In the first component, plastic waste generation will be estimated considering the population growth rate and its per capita waste generation rate (Hanandeh et al., 2010). In the second component, a Gated Recurrent Unit (GRU), was trained with COVID-19 historical data from BMA in Colombia. Afterwards, this model is used to predict the subsequent dynamics of the COVID-19 pandemic in the BMA.

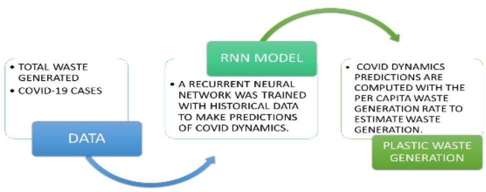

Figure 2: Schematic diagram of the proposed model. The estimation of plastic waste generated during the COVID-19 pandemic is based on a RNN model associated to the sanitary emergency dynamics and a plastic waste generation model.

2.1 Gated recurrent unit (GRU) Model

The GRU is a type of Recurrent Neural Network (RNN), which consists of numerous successive recurrent neural layers. These layers are sequentially connected in order to embed the time sequence as an internal state. GRU has a strong capability in order to capture the contextual data from the sequence. However, the contextual cues in the network structure are stable and are effectively used to achieve the data classification process (Kumaraswamy et al., 2021). GRU networks were designed specifically to overcome the long-term dependency problem faced by RNNs (due to the vanishing gradient problem). In this work, the GRU model contains an input layer (64 neurons, shape (30,1)), four hidden layers (128, 256, 128, 64 neurons), and an output layer (1 neuron, shape (1,1)). This architecture can be broadly thought of as an encoder network followed by a decoder network. The GRU model was trained with data from new COVID-19 cases in the BMA from 1 May 2020 to 30 September 2021. First, the data is normalized according to the population in the region, and a moving average filter is applied to reduce its noise. Then a windowing process is performed, which consists of dividing the data into subsequent 30 d windows. The GRU model is trained to predict the normalized amount of new COVID-19 cases on day 31.

2.2 Waste Generation Model

The waste generation model uses data of the waste generation rate per capita and the population growth rate for the city of Bucaramanga, Colombia. Historical data from the last three years before the pandemic (2017-2020) was used to adjust both the waste generation rate per capita and the population growth rate (Figure 4). Also, another input of the model was the number of estimated new COVID-19 cases. This information was used in the integrated model to adjust the percentage of plastic waste in the per capita MSW generation rate as a function of the number of healthy and infected individuals. For the healthy people, the percentage from the sectoral report on waste management activities is used (29.72 %). For infected individuals a significantly higher percentage (40 %) was used taking into account the high correlation observed in hospitals between the amount of medical waste, hazardous waste, with the number of COVID-19 infected individuals (Yu et al., 2020). On the other hand, the updating rules used in the proposed waste generation model are listed below:

$$WGR = WGR_{Initial} \times (1 + wggr)^k \quad (1)$$

$$Pop = Pop_{Initial} \times (1 + pgr)^k \quad (2)$$

$$WQ = \big((I \times Pop) \times WGR_{Inf}\big) + ((1 - I) \times Pop) \times WGR \quad (3)$$

Where the waste generation rate (WGR) in a simulation iteration (k) is obtained from the relationship between the initial WGR and the waste generation growth rate (wggr). The estimated population at iteration N is computed by using the population growth rate (pgr). An estimation of the amount of waste quantity at time k (WQ) Eq(3), is computed by considering the prediction of people infected by COVID-19 (I), the waste generation rate of an infected individual (WGRinf) and the estimates of equation Eq(1) and Eq(2).

3. Case Study

Open access for data associated to COVID-19 during the pandemic has been a common policy in several countries around the world, including Colombia. This data is usually acquired on a daily basis and it is rapidly consolidated within a couple of weeks. On the other hand, information associated to plastic waste is not rigorously monitored in Colombia, and it is acquired at monthly basis. Both public resources were available and they were used for training and adjusting the components of the models. Mainly, we used two different data sources described in detail in the following.

3.1 COVID-19 Epidemics Dataset – Bucaramanga Metropolitan Area (BMA)

Data associated to the COVID-19 cases and deaths in Bucaramanga Metropolitan Area (BMA) was extracted from an open access dataset published by the Colombian government (Instituto Nacional de Salud, 2020). The dataset includes information of positive COVID-19 cases for each town in Colombia. For each case in the dataset full information regarding the location, gender, status, date of notification, date of death, among other data of the infected person is available. In the present work, only the columns "Name of municipality", and "Date of notification" were used for the computation, because only the number of cases per day in each municipality was needed. After calculating the cases/d, a 7 rolling window was applied to reduce the noise and smoothen the time series, as observed in Figure 3.

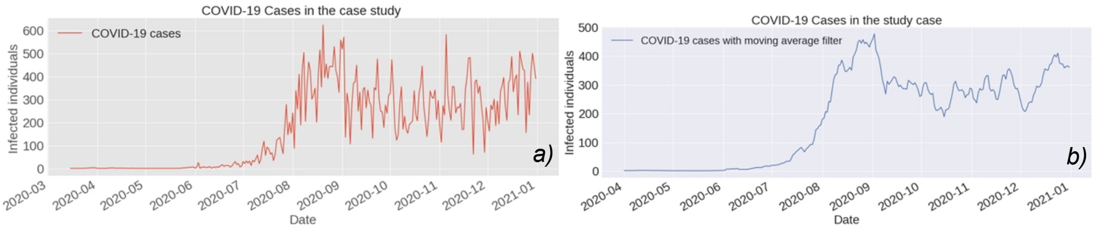

Figure 3: a) COVID-19 confirmed cases in the Bucaramanga Metropolitan Area (BMA); b) Filtered data of COVID-19 confirmed cases in the BMA with a 7 d rolling-window. Data corresponds to the cases from April 2020 to January 2021 in the BMA, which includes data from 4 different municipalities extracted from the Colombian National Health Institute (Instituto Nacional de Salud, 2020).

3.2 Total and recyclable waste in the BMA

The historical data associated to total waste in BMA was retrieved from the Single Public Utilities Information System (SUI) platform, which is used by the Superintendencia de servicios públicos domiciliarios, a colombian government agency dealing with residential public services. This dataset contained the amount of total recyclable waste from all cities in Colombia, including the municipalities composing the BMA (Figure 4a).

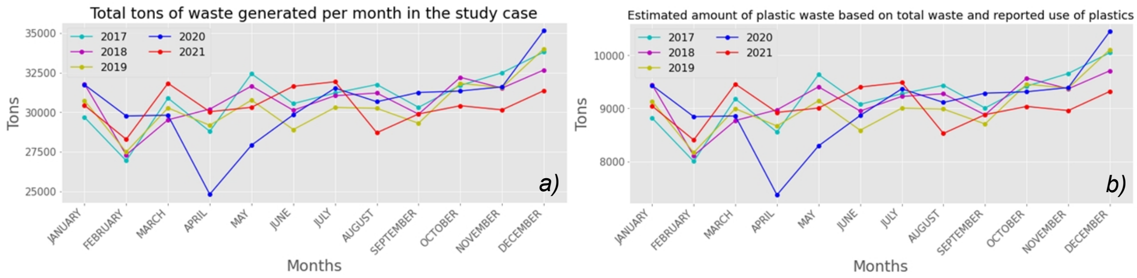

Figure 4: a) Total t of waste generated per month in the municipalities composing the BMA; b) Estimated amount of plastic waste generated per month for the BMA

Additionally, information from the sectoral report on waste management activities was also used (Superintendencia de servicios públicos domiciliarios, 2021). This report includes regional trends on solid waste management in several regions of Colombia, waste generation by type of material, percentage of plastic waste in the total amount of waste collected, among others. For this study, we retrieved the percentage of plastic in the total waste for Santander, in which the BMA is located. The plastic waste percentage of 29.72 % was found for the BMA (Figure 4b).

4. Results

This section will explain the results by analyzing the predictive capability of the GRU model and subsequently integrating it with the waste generation model.

4.1 GRU validation results

Table 1: GRU model results in different time windows, evaluated with the average of the Mean Absolute Error (MAE) in the interval from 1 October 2021 to 31 December 2021.

GRU neural network window-size		
15 d	30 d	45 d
4248.25	1035.89	1584.59

In Table 1, the results for several GRU models in the prediction of the total amount of COVID-19 cases is reported. Mean absolute error for a total of 92 d forecast show that the best model was trained with a window-size of 30 d. Figure 5a shows the one step-time prediction and evaluation on the training data. Figure 5b shows the prediction for 3 months (October to December 2021) generated by the GRU model based on 30 input data (corresponding to the 30 d window). The prediction by the GRU model resembles the real data with many dips and rises, but it still has noticeable differences. This is because the model uses a different forecasting methodology called point-to-point, which ensures that the model does not know the data to be predicted and only takes into account what it learned in the training period. Traditional prediction functions found in Python libraries do not use such a methodology, so the model knows the data to be predicted beforehand and lacks reliability (giving at the same time better results).

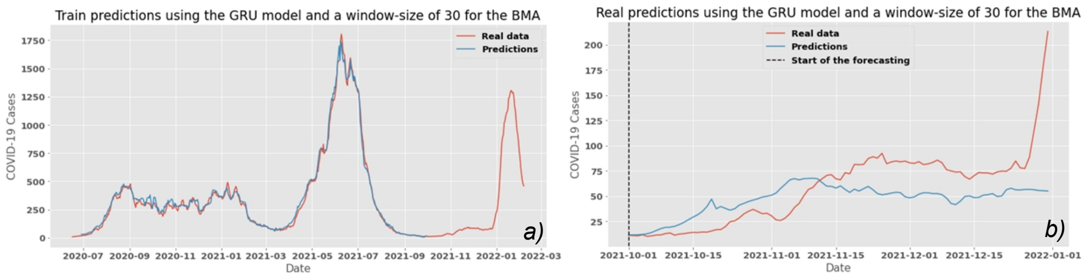

Figure 5: a) One step–time prediction on the training data showing that the model COVID-19 properly captures the information on the training data; b) Predictions of the GRU model for COVID-19 cases on the BMA for a three-month evaluation window (1 October 2021 to 31 December 2021). Only information associated to the 30 d before the start of the forecast is fed into the model.

4.2 Waste Generation Model Results

Figure 6a shows the simulated amount of solid waste generated for the same period predicted by the GRU to vary the per capita waste generation rate depending on the infected population.

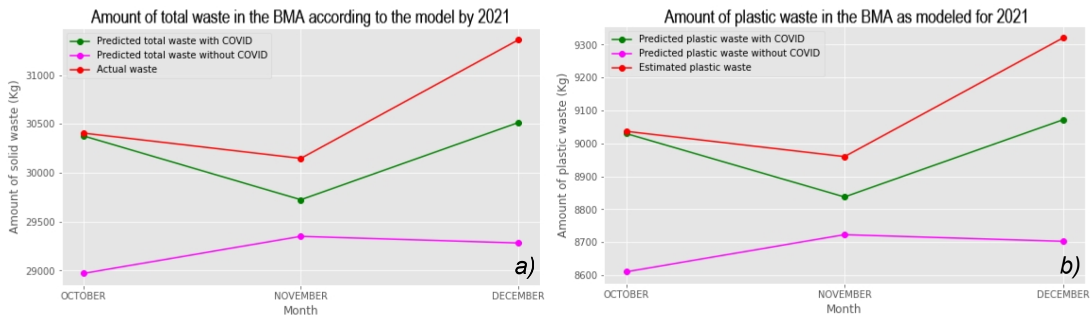

Figure 6: a) Amount of total waste in the BMA as modelled for Oct-Dec 2021; b) Amount of estimated plastic waste in the BMA as modelled for Oct-Dec 2021.

Figure 6b shows the plastic waste for the simulated model. The results show that the simulation in a COVID-19 scenario leads to a slight increase (10 %) in plastic waste generation. However, further analysis is needed to determine if under different conditions these simulated results are significantly different.

5. Discussion and conclusions

The main assumption in our work for simulating plastic waste generation is that populations with different sanitary status (healthy/infected) have different waste generation rates. Specifically, an infected individual generates a higher amount of waste than that generated by a non-infected individual. This assumption is based on statistical analyses: During the pandemic, in a day, generation rates were even up to 10 times greater than those observed in normal conditions (Abu-Qdais et al., 2020). Other analyses report a moderate change, with a waste generation rate of 0.6 kg/bed for uninfected patients, and 2.5 kg/bed for patients infected with COVID-19 (Yu et al., 2020). Although these hypotheses are well established for patients in medical facilities, they may be an oversimplification to generalize to persons with milder symptoms.

Our proposed model also includes two subcomponents to model the sanitary emergency dynamics and the waste generation in an independent way. The RNN model is used to characterize the behavior of the epidemic in a specific urban region, learning from the associated historical data. In the epidemic dynamic forecast, the predictions and actual values are different due to both the length of the observation window (three months). The model manages to capture general trends that resemble what was seen in the train period, but has significant differences that become evident in timepoints that are far away from the start of the forecast.

We should also mention that the model is trained by using the available data in the historical record previous to the evaluation time interval. Although the effects of new variants, vaccinations, and political measures were not explicitly fed into the model, it should be noted that the training data is tailored to a specific region, and it is expected that the model will incorporate the effects of such specific variables in an implicit way.

Finally, data on plastic waste during health emergencies is paramount for evaluating its environmental impact. However, due to the lack of guidelines for acquiring this data, this information is often unavailable, particularly in developing countries. This work uses an integrated model to simulate the plastic waste generation process during sanitary emergencies, which could later be extended and applied in other urban regions and cities with similar conditions to the case study. Results show plausible scenarios of plastic waste increase (10 %) in the mentioned sanitary emergencies that resembles the actual data. Also, the model forecast had a mean absolute error of 0.62 t for the three months in the evaluation time interval.

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