A Simple Algorithm for Anti-venom Distribution

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Abstract

Despite being a major health problem, snakebites in Colombia are not managed as a neglected tropical disease, leaving the distribution of antivenom to the regular structure of the health system. This strategy leads to a lack of inventory and control of the supplies, increasing the probability of patient displacement, local antivenom shortages and deaths due to lack of treatment. We propose an algorithm that analyzes snakebite incidence rates, health centers and geographic data to achieve two main objectives: grouping municipalities into patches, and an antivenom distribution strategy for these patches. Grouping was done with a grid system that ensures ready treatment, minimizing the amount of hospitals that need antivenom for full coverage. For the distribution algorithm, three strategies were evaluated: equal distribution, random/lottery distribution and an incidence rate distribution. Results show that a grouping algorithm ensures access to treatment and minimizes patient displacement, while the incidence rate distribution strategy optimizes the use of available antivenom. In view of this, a regulated antivenom distribution policy managed by public health authorities is necessary in order to ensure full coverage with minimal deaths and optimal use of antivenom stock in Colombia.
1 Introduction

Snakebite, in the words of professor of tropical medicine David Warren, is the most neglected of neglected tropical diseases, and poses a serious issue worldwide [14]. Even though it is not an infectious condition, the World Health Organization declared snakebite a neglected tropical disease in 2009 due to the lack of attention given to the problem in policy and pharmaceutic research [10]. This situation of neglect exists despite the magnitude of the public health problem posed by snakebite worldwide, especially in lower-income, tropical countries. Global estimates of snakebite incidence have been as high as 1,841,000 cases per year, while mortality is estimated to reach up to 94,000 yearly deaths [13]. Public perception of snakebite tends to underestimate the magnitude of the problem when compared to other tropical diseases, however, the number of deaths caused by snakebite in fact doubles that of Chagas disease or leishmaniasis, and in fact rivals that of dengue and yellow fever [15].

Snakebite is particularly a problem in Colombia, which sees around 4,500 reported cases of snakebite envenoming every year [8]. Colombia has an incidence rate of 8.6 cases per 100,000 inhabitants [6], a relatively small number when compared to neighboring countries such as Ecuador (10 cases per 100,000 inhabitants) or Brazil (16 cases per 100,000 inhabitants) [13]. However, incidence rates vary widely across the country, with some departments reaching over 90 cases per 100,000 inhabitants [6]. Furthermore, it is widely believed that snakebite underreport is rampant in Colombia, particularly in cases of death, since these patients never reach a health center and go unaccounted for [17]. Nevertheless, reliable estimates on the extent of underreport and the true burden of snakebite in Colombia are still lacking.

Snakebite, unlike other tropical diseases, has high mortality and morbidity rates, and thus needs proper health care and antivenom administration immediately after a bite. Because of this, a robust antivenom distribution strategy is needed to achieve the maximum possible coverage. Distribution of snake antivenom in Colombia is ordinarily managed through private health providers (Entidades Promotoras de Salud, EPS), responsible for the acquisition and distribution of antivenom according to its demand within the health centers under their jurisdiction [16]. In consequence, there is no unified inventory of antivenom distribution in Colombia, and each producer manages the distribution of its own antivenom. Additionally, in periods of antivenom shortage, the Emergency and Disaster Group of the Ministry of Health distributes a strategic stock of antivenom through Regulatory Centers of Emergencies and Disasters (Centros Reguladores de Emergencias y Desastres, CRUE) in each department according to epidemiological data [16]. This strategic stock is particularly relevant in Colombias present situation: the country has been in a state of public health emergency due to antivenom shortage for the past twelve months, and the state of emergency has been recently extended to last for at least another year [7]. Due to this confusing, fragmented distribution system, antivenom is often unavailable in regions where it is needed. This is a problem for many neglected tropical diseases, as well as other expensive medical treatments around the world [18, 2, 12].
Therefore, there is a need to establish a distribution policy to optimize storage availability, inventory of isolated regions in high risk areas, and organization of health centers.

Medical supply distribution strategies have been researched in detail over the past years. The problem has been framed in many different ways depending on the context and constraints imposed, and thus, many different approaches have been developed to solve the problem \[21, 20, 3, 19\]. One such approach is the construction of maximum coverage models. Coverage models, applied in commercial scenarios as well as medical distribution problems, are used to ensure all users of a given service have access to a facility that provides this service. A variety of different constraints can be imposed, such as having a given network of set facilities instead of placing them according to convenience \[5, 22\], or minimizing the amount of facilities necessary to achieve adequate coverage \[21\]. These studies use optimization techniques on a set of mathematical equations to determine some aspect of the overall problem. Important parameters included response time or distance, population density, incidence rate, and spatial location.

Mathematical and computational tools such as the ones mentioned above are valuable assets in the limited-resource context of neglected tropical diseases in the developing world, due to the fact that they allow the best possible distribution of whatever scarce resources are available. This is especially true in the case of snakebite, given the necessity of strict response time. In light of this, the aim of this project is to use statistical methods and network theory to develop an optimization strategy for snake antivenom distribution in Colombia, based on current transportation networks and epidemiological data. Building on previous coverage models, we propose a general algorithm that can determine which medical facilities are important to the coverage network, but also how many doses of antivenom should be allocated to each of them.

2 Materials and Methods: Constructing the Algorithm

Antivenom can be very expensive \[4\]. Regardless of the total amount spent on antivenom in Colombia, the fact is that antivenom is a limited resource, and each vial must be used efficiently. If vials are unused in one area and needed in another, a situation of dead stock is created. This reason why a distribution strategy, a way of deciding which regions receive antivenom and how much each should get, is needed.

Weekly reported snakebite incidence for each municipality in Colombia within the period of January 2007-May 2015 was obtained from the Colombian National Institute of Health’s vigilance program \[11\]. Municipalities only report if there are any snakebites that year. We assume that if they did not report that year then the incidence rate is zero. We average the total incidence rate of each municipality from 2007 to 2015. Since our goal is to distribute antivenom across Colombia, we use a map in the form of a PolygonShapeFile developed by Maurix Suárez.
Our algorithm has two objectives. The first is to group regions (in this case, the municipalities of Colombia), so that we minimize the number of facilities or health care centers that need antivenom delivered to them. The grouping algorithm was built with constraints: we have to insure that all the regions have access to a hospital. This means that envenomed patients must be able to reach a hospital before they die. In set coverage models, this is sometimes referred to as a maximum response time; in our algorithm, this is defined as time to death.

Our approach uses a grid system that assigns each region a column and row number. The height and width of each square on the grid is created based on average time to death. Our algorithm ensures that if a person is bitten, they can reach any other point inside their patch before death. Thus, only one hospital per patch is needed on the grid. This is different than a traditional set coverage model in that since our constraint lies on the grid, rather than the distances between individual regions and hospitals.

A concern with grouping the regions is being sure information about the individual regions is carried over. Our algorithm is able to carry the incidence rates from each municipality to the group hospital. This can be done similarly for other types of data, but is particularly useful for developing our distribution strategies. We want to test this against other possible networks. The two we used are based on the political divisions in Colombia at the municipality level and the department level. Our grouping algorithm is outlined using pseudo-code in Algorithm 1.

The second goal of our algorithm is to distribute antivenom on this grid map. As we have stated, there is currently no rational strategy for antivenom distribution in Colombia. Since there is no benchmark in Colombia we evaluated three strategies for the sake of comparison: equal distribution, random or lottery distribution, and an incidence rate distribution. Equal distribution gives the same amount of antivenom to each region. A lottery distribution assigns a random number of antivenom to each region. The final strategy distributed antivenom based on the incidence rate for each region.

Once the antivenom is distributed, the success of each strategy must be quantified. To do so, we estimate the number of deaths in each patch on the basis of the average number of cases in each patch, the average number of doses of antivenom used per case and the amount of antivenom allocated to each patch, and real data for 2014: in 2014, 15426 vials of antivenom were used, and an average of 4.6 vials are needed per snakebite [1]. From this and the data on incidence rate we can estimate deaths due to untreated reported snakebites. As an example of a distribution strategy, our incidence rate distribution algorithm is outlined using pseudo-code in Algorithm 2.

These two algorithms together hope to optimize the placement of antivenom as well as minimize the number of hospitals needed for full coverage of Colombia.
3 Results

Based on our algorithm and the data for snakebites in Colombia, we were able to group municipalities based on our grid system. We are able to keep track of all individual characteristics of each municipality, such as incidence rate, location, deaths, and amount of antivenom. We proposed three types of distribution strategies on three different networks. The networks are at the municipality level, the department level, and our grid-based algorithm network. On each of these networks, we test an equal distribution of antivenom, a random distribution, and a distribution based on incidence rates in the area.

Figure 1 show three sets of maps with the different distribution strategies.

We want to minimize deaths by finding the best distribution strategy with a limited amount of antivenom. In Table 1, we show the total deaths for each of the possible combinations. A second concern is if there is any dead stock, or unused antivenom. In Table 2, we show the total number of available treatments that were unused because the antivenom is in the wrong region.

Table 1: Total Deaths For Each Combination of Distribution and Grouping

<table>
<thead>
<tr>
<th>Group</th>
<th>Distribution</th>
<th>Equal</th>
<th>Random</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipality</td>
<td>Equal</td>
<td>2048.085</td>
<td>2187.342</td>
<td>355.0946</td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incidence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State</td>
<td>Equal</td>
<td>1184.332</td>
<td>1370.347</td>
<td>355.0946</td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incidence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algorithm</td>
<td>Equal</td>
<td>1918.109</td>
<td>1792.496</td>
<td>355.0946</td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incidence</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Total Treatments Left Over From Dead Stock

<table>
<thead>
<tr>
<th>Group</th>
<th>Distribution</th>
<th>Equal</th>
<th>Random</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipality</td>
<td>Equal</td>
<td>1692.9900</td>
<td>1832.247</td>
<td>0</td>
</tr>
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<td></td>
<td>Random</td>
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<td></td>
<td>Incidence</td>
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<tr>
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<td>Equal</td>
<td>829.2375</td>
<td>1015.253</td>
<td>0</td>
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<tr>
<td></td>
<td>Random</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incidence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algorithm</td>
<td>Equal</td>
<td>1563.0142</td>
<td>1437.402</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Random</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incidence</td>
<td></td>
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</tr>
</tbody>
</table>

4 Discussion

Our goal for developing these algorithms is to minimize the amount of deaths due to snakebites. We see from the results that incidence rate distribution minimizes deaths in all three groupings. This supports the current distribution strategy in Brazil, which also takes into account incidence rate as part of their antivenom distribution equation [9]. Even though we did not use linear optimization strategies in our algorithm, we note that in the incidence rate distribution there is no dead stock, thus
every vial of antivenom is used: even this simple formula is enough to use all available stock to its maximum potential.

One important characteristic of our algorithm is that it ensures full hospital coverage of Colombia (given that there is a single hospital per region). In the case of grouping by municipality (no grouping), it may be too costly or inefficient to send antivenom to individual municipalities. In the case of grouping by department, it is not necessarily true that Colombia has full hospital coverage. Southern Colombia is broken into more regions in our algorithm’s grid division when compared to the department map. This could lead to unnecessary deaths if using the department distribution, where the victim might be too far away from any hospital to be treated.

Dead stock, as shown in Table 2, is a serious issue for any treatment. In this case, dead stock means someone may die because the vials are not distributed correctly. This could be a problem economically if too much antivenom is produced, but is more serious in the case of limited supply.

4.1 Limitations of the Algorithm

As stated earlier, set coverage algorithms are well studied and have accomplished similar goals. Many of them take space and response time into account explicitly. Our algorithm does not, but instead uses the grid system with response time implicitly. This may cause the total number of hospitals needed to increase, because it is not a true optimal. These set coverage algorithms need more information than our algorithm, such as locations of hospitals and regions as well as distances between each pair of points. Our algorithm only requires information of the regions under consideration. We do not need information on the distance between each region, just a desired response time. This is a huge advantage for developing countries where data collection is not as accurate or unavailable.

With this, we also assume that each region has at least one hospital. This is not the case for southern Colombia. Many of the regions in the Amazon do not have access to a hospital and seek traditional methods. This is a problem for reducing snakebites in general, but also brings attention to the need for hospitals isolated regions. Our algorithm tells us that if there is a single hospital in each of those regions, we can reduce the number of deaths overall.

4.2 Future Work

This algorithm was intended to be generally applicable. A goal at the start of this project was to develop an application that allowed users to enter their data and see plots and results similar to the ones in this paper. This could give other countries with other diseases a perspective on the type of distribution strategies they should be using.

One assumption of our model is that we use one type of antivenom. In Colombia, there are two main species of snakes responsible for snakebite accidents, and thus two types of antivenom needed. It would be interesting to find an optimal way of distributing antivenom given the distribution of these two snake species across Colombia.
The fact that we do not mention cost in our algorithm is important to take into account. There is a cost associated with every step in producing the antivenom. Since we do not know the cost of a vial, we cannot say how large the budget should be for full coverage [UPDATE THIS WITH NEW INFO FOR NEXT DRAFT]. We cannot say where each hospital should be located in order to optimize delivery and storage costs. We did not have data on the size of the hospitals, which could influence which hospitals are kept open.

Antivenom distribution has to be conceived dynamically wherever feedback and reports are essential to improve performance. For this reason, the inclusion of new variables, such as climatological and social factors as well as underreporting, is of high importance. Strategies that use this information could lead to better distributions. Similarly, public health events that need to be highly controlled and regulated can be managed with network models as shown previously.

5 Conclusion

We have shown that with proper distribution of antivenom and an optimal placement of hospitals, it is possible to minimize deaths and use treatments to their maximum potential. Though others have tackled this issue before, our algorithm requires less information and computations in order to work. Not only can this be used for diseases in developing countries, but to other problems dealing with resource allocation in low information settings.

To address the problem of snakebite, it is necessary to develop an integrated policy that involves vigilance of cases, antivenom production improvements, investment, treatment accessibility and recovery support [9]. As Ospina [16] exposes, there is a need to establish a distribution policy to optimize storage availability, inventory of isolated high incidence regions and organization of health centers. We hope this work gives reason for the Colombian Ministry of Health to regard snakebites as a neglected tropical disease in order to design specific health plans of monitoring, treatment and prevention, in order to optimize attention of the condition and a better allocation of economic resources.

Acknowledgments

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Algorithm 1 Grouping Algorithm

1: procedure Create attributes
2: \( \text{IncRate} \leftarrow \text{Incidence rate of each area} \)
3: \( \text{lat} \leftarrow \text{Latitude of each area} \)
4: \( \text{lon} \leftarrow \text{Longitude of each area} \)
5: \( \text{TimeToDeath} \leftarrow \text{average time till death from a snakebite} \)
6: \( \text{TotalVials} \leftarrow \text{Number of vials available for the country} \)
7: \( \text{PerTreatment} \leftarrow \text{Number of vials needed per snakebite} \)
8: \( \text{GridSize} \leftarrow \text{Creates grid based on \( \text{lon, lat} \)} \)
9: \( \text{AreaCode} \leftarrow \text{Area code for each area based on \( \text{GridSize, time.to.death} \)} \)

10: procedure Group Areas
11: \( \text{loop:} \)
12: \( \text{for each unique AreaCode do} \)
13: \( \text{Find areas with AreaCode} \)
14: \( \text{AbArea} \leftarrow \text{Area with max IncRate} \)
15: \( \text{AbArea’s IncRate} \leftarrow \text{sum of areas IncRate} \)
16: \( \text{Set all other area’s IncRate to zero} \)
17: \( \text{goto loop.} \)
18: \( \text{close;} \)
19: \( \text{ReducedNetwork} \leftarrow \text{areas with incidence rates > 0} \)

Algorithm 2 Anti-venom Distribution Algorithm

procedure Incidence Rate Distribution

2: \( \text{TotalInc} \leftarrow \text{sum(IncRate)} \)
3: \( \text{Percentage} \leftarrow \text{divide each areas IncRate by TotalInc} \)
4: \( \text{Treatments} \leftarrow \text{Multiple each areas VialsEach by PerTreatment} \)
5: \( \text{Deaths} \leftarrow \text{subtract IncRate from Treatments} \)
6: \( \text{if Deaths is negative then set it to zero} \)
Figure 1: We distribute antivenom on these maps. The first row of maps shows Colombia at the municipality level, the second at the department level, and the third based on our algorithm. Each column is a different distribution strategy. The first is equal distribution, the second random, and the third based on incidence rate. The shade of red indicates the number of deaths in each region. For total number of deaths for each map, see Table 1.
References

[10] INS. Vigilancia rutinaria por eventos municipal.