Recommendations for a new sanitation risk index and geospatial visualisations to aide decision making in Antananarivo, Madagascar

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Key Acronyms

AHP                Analytic Hierarchy Process
CUAS               5ème Arrondissement Commune Urban d’Antananarivo
SDP                Sanitation Data Platform
SRI                Sanitation Risk index
WASH               Water, Sanitation and Hygiene

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Geovation, Sutton Yard, 65 Goswell Road, London ECTV 7EN

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1. Executive Summary

- Indices have been used to enable data-driven decision making in numerous sectors around the world. They help us track changes in complex environments over time and identify where interventions may be necessary or valuable.

- Improved indices would help decision-makers understand where the lack of sanitation provision is posing greatest risk to communities and therefore where investment is most needed. This is more than a baseline: the index would provide insight by analysing data to create geospatial visualisations that show priority areas.

- A new sanitation risk index (SRI) will need to be implemented by sanitation organisations operating in the same location if it is to help inform action and be used to assess the potential risk reduction achieved by different sanitation related investments as part of a cost-benefit analysis.

- One of the biggest challenges for improving data-driven decision-making in the sanitation sector is the availability of useful datasets. SRIs rely on the information that feed into them, so the sanitation sector will need to continue to work to improve the quality and integrity of datasets.

- We have designed three risk indices. These indices each combine the same set of 13 indicators in different ways to predict the level of risk of uncontained faecal waste in the environment in the 5eme arrondissement in Antananarivo (the 5th district, abbreviated to CUAS). Despite the quality of the data, the outputs of the SRI in this report are still useful to demonstrate what can be created, and we will continue to work with stakeholders to improve the quality of the data.

- The three indices we have outlined above all use different formulae and produce slightly different predictions of the areas of highest and lowest risk. All three predict areas of high risk in the north of CUAS, particularly in the fokontany of Alarobia. All of the indices closely follow the levels of open defecation across the study area.

- There is no dataset that shows the level of uncontained faecal waste in the environment in CUAS. In lieu of this dataset, we asked experts from several sanitation providers working in Antananarivo for their perception of the level of sanitation risk across our study area.

- We want to ensure that the insight we produce is useful and accessible to decision-makers. To enable users to access, interact with and feedback on our work, we are hosting geospatial visualisations of the SRI on an online sanitation data platform (SDP).

- We will continue to build on the work we have done as part of this project, improving our analysis and making our work useful and accessible. We will particularly focus on collaborating with local stakeholders, decision makers and experts in Antananarivo to
develop our sanitation risk indices, visualisations and sanitation data platform. We plan to take these steps as part of our UK Aid Direct-funded project to launch a Sanitation Data Hub in Antananarivo. This project will allow for continued stakeholder engagement, data collection and the refining of the standard, index and platform.
2. Introduction

1.1. This project

This report is the final stage of the project “Assessing the accessibility of urban sanitation data in Antananarivo, Madagascar” undertaken by Gather for the World Bank Development Economics Data Group’s (DECDG) Trust Fund for Statistical Capacity Building (TFSCB).

This project is responding to the fact that:

- There is no inventory of publicly available urban sanitation data focusing on Antananarivo, Madagascar;
- There is also no agreed data standard for the collection, storage and management of publicly available sanitation data which impedes the sharing and curation of sanitation data;
- Available sanitation data is often not analysed alongside geospatial datasets to create a more useful baseline analysis of sanitation needs.

In response, we are:

- Curating and assessing publicly available sanitation data from open sources to identify the sanitation data gap. We published the report The Sanitation Data Gap in Antananarivo, Madagascar in April 2020;
- Creating a scheme of work for the standardisation of sanitation data—this was the focus of our previous report Recommendations for the design of a data standard for sanitation data, published in June 2020;
- Performing geospatial analysis on available sanitation data to create visualisations to help decision-makers (the focus of this report).

The project covered the Sustainable Development Goals 6 (clean water and sanitation), 11 (sustainable cities and communities) and 17 (partnerships for the goals).

1.2. This report

In our previous report Recommendations for the design of a data standard for sanitation data, we looked at how data standards could be used in the water, sanitation and hygiene (WASH) sector and put forward recommendations for the design and adoption of a data standard for WASH data.

In this report, we:

- Explore how risk indices have been used in other sectors to direct interventions and the allocation of resources over space and time, and review some existing risk indices that have been used in WASH;
• Outline three sanitation risk indices that we have developed based on existing indices, and propose a fourth index to test, validate and develop with our users;
• Consider the impacts of data availability and quality, and make recommendations on how to automate data sharing to improve data availability;
• Summarise the creation of a sanitation data platform that hosts geospatial visualisations that were created using the sanitation risk index.

1.3. Location of this work

The work in this report focuses on the 5ème arrondissement in the city of Antananarivo, Madagascar.

Figure 1. Map to show the location of the 5ème arrondissement in Antananarivo, Madagascar. The inset maps reveal the location of Antananarivo within Madagascar.
3. Existing sanitation risk indices

In our two previous reports, we outlined a methodology for assessing the sanitation data gap and recommendations for the adoption of a new data standard for sanitation data. In this report, we present how a sanitation risk index (SRI) can translate standardised data into geospatial visualisations that can be used by decision makers in Antananarivo, Madagascar to understand the priority areas for investment into sanitation.

In this report, we define indicators as quantifiable characteristics of a population or area. Indicators allow us to monitor and track complex environments by focusing on specific elements that together represent the whole: “indicators are a way of seeing the big picture by looking at a small piece of it” (Plan Canada 1999). A dataset is the output of a survey designed to collect information on a particular indicator or indicators.

In this chapter we explore existing indices and considerations for the design of our sanitation risk index.

3.1. Indices

Indices have been used to enable data-driven decision making in numerous sectors around the world. They help us track changes in complex environments over time and identify where interventions may be necessary or valuable.

3.2. Lessons from outside the sanitation sector: normalised difference vegetation index

Indices have been transformative in the agricultural sector. A vegetation index measures plant greenness, which is an indicator of plant or vegetation health (United States Geological Survey 2019). The normalised difference vegetation index (NDVI) is widely used in agriculture to assess population and changes to biodiversity in climate (Pettorelli, et al. 2011). It uses earth observation data to monitor how much visible light is absorbed and how much near-infrared is reflected by leaves. It adds in data on light levels, surface slope, exposure, and other external indicators, and incorporates all this data into an index which shows how healthy crops and individual plants are (Earth Observing System 2020).

The Crop Monitoring application has integrated the NDVI to facilitate crop tracking. Farmers use this insight to identify high-productivity areas in a field against those which require additional treatment, and to irrigate and fertilise different areas of the field to maximise crop yield. The NDVI also enables farmers to track crop growth over time, both throughout the season and across years (Earth Observing System 2020).

The NDVI shows how indices allow us to derive insight from geospatial environmental and earth observation datasets and direct targeted interventions to where they are needed most. In the sanitation sector, this kind of insight can empower local governments and decision-makers to direct their investments efficiently and see the effectiveness of their investments over time.
3.3. Components of a sanitation risk index

Just as the NDVI is used by farmers to identify crops requiring treatment, we can use indices to understand where a lack of sanitation provision is posing greatest risk to communities and therefore where investment is most needed. This is more than a baseline: an index provides insight by analysing data to create geospatial visualisations that show priority areas.

The element of risk is key to identifying priority areas for investment for sanitation. A risk index is a numerical representation of risk. Risk can be calculated in a multitude of different ways, but the different elements of risk are usually grouped into a few key components (e.g. hazard, exposure) which are described by a number of relevant indicators (e.g. toilet density, flood risk) (Campos, et al. 2015). These components and indicators are chosen based on coherence with the framework, minimising overlapping (potential correlation between factors), and availability of data. The larger and higher the quality of datasets that are available in an area, the more reliable the results are: better data means better insight. The indicators are combined to give a risk score for each component and then the components are combined to give an overall risk score.

In this report we follow a disaster risk management approach and situate sanitation risk in the intersection of hazard, exposure and vulnerability (see Carreño and Cardona 2007; Peduzzi, et al. 2009).

![Figure 2. Intersection of hazard, exposure, and vulnerability yields the risk](image)

Hazard considers sources of potential harm to communities, and the likelihood of a hazardous event occurring. For sanitation, Campos et al explain:

“...Toilet facilities and infrastructure in the sanitation service delivery chain are designed for containment, transportation and treatment of human waste. If a system is complete and in good working order, then there is very little risk because faeces containing...
pathogens are kept isolated from residents. On the other hand, if the system is incomplete or not functioning, then there is an increased probability of a hazardous event, caused by the emission into the environment of pathogens. The frequency and extent of hazardous events are primarily determined by the coverage and quality of the sanitation system – the lower the coverage and the quality, the higher the frequency and extent of these hazardous events.” (2015, 375)

Exposure focuses on the type and intensity of contact between the hazard and individuals within local communities. Within sanitation it measures how individuals are exposed to faecal contamination and the duration of this exposure (Campos, et al. 2015).

Vulnerability-coping capacity refers to the susceptibility of individuals to suffer harm from hazardous events. For sanitation, this usually refers to sanitation-related illness such as cholera, and the effect that this illness or disease have on an individual’s health. Vulnerability-coping capacity is closely linked to socio-economic indicators. Poverty directly affects an individual’s health and how they are able to overcome or cope with diseases (Campos, et al. 2015), and indicators such as class, gender and disability increase vulnerability to the risk of sanitation-related diseases (Wisner, et al. 1994).

Sanitation risk indices therefore need to incorporate a variety of indicators to ensure they can provide accurate and complete assessments of the level of sanitation risk in a community.

3.4. Existing sanitation risk indices

Several risk indices already exist for the sanitation sector. Here we explore three of them: the Rapid Participatory Sanitation System Risk Assessment (RPSSRA); the Urban Sanitation Status Index (USSI); and the Faecal Contamination Index (FAECI).

3.4.1. Rapid Participatory Sanitation System Risk Assessment (RPSSRA)

The Rapid Participatory Sanitation System Risk Assessment (RPSSRA) uses local stakeholder knowledge to provide an overview of the rate of sanitation risks within communities. It calculates sanitation risk as the sum of hazard, exposure and vulnerability (Campos, et al. 2015). The hazard is considered as faecal contamination of the environment; exposure is the level of community exposure to this hazard; and vulnerability is the indicators that exacerbate the impacts of infection.

In their RPSSRA study, Campos et al (2015) gathered data through conducting workshops with local residents who assessed the average conditions in their local area. They did this by assigning a risk score of one, two or three to various indicators such as: condition of latrine facilities (hazard), sharing of latrines (exposure), and housing condition (vulnerability). The boundaries of the different areas which were assessed were defined by considering physical features that could constitute a boundary and change in settlement type. (Whilst this approach works well when conducting workshops, it may be difficult to apply to a secondary data-based study.) To validate the results from the workshops, 160 sanitary survey forms were
completed which expanded upon the indicators considered during the workshops. From the surveys, a risk score could be calculated in the same way and compared to the results.

The RPSSRA has a robust framework whilst maintaining relative simplicity (Haruna, Istifanus and Muh’d Isa 2017). Campos et al’s (2015) study highlighted the importance of defining low, medium and high risk, as the way in which these classes are defined is critical to the study’s success and validity. The RPSSRA technique uses the component and indicator design, which allows for flexibility as the indicators can change spatially and temporally, as long as the theoretical robustness is maintained (Campos, et al. 2015). The lessons we have learnt from the RPSSA index has been formative in the formulation of the three indices we will present in chapter 5. We have been able to incorporate how Campos et al have defined calculating risk into our index.

3.4.2. Urban Sanitation Status Index (USSI)

The USSI is a tool developed by the Water and Sanitation Program (WSP) and is predominantly utilised for public services such as the transport and treatment of faecal waste (Hawkins and Muximpua 2015). This index was created to aid planners and managers in knowing where to prioritise. It is used to measure the sanitation statuses at local and municipal levels. The key indicators for analysing sanitation status are divided within components such as containment; emptying and transport; treatment and disposal, and complementary services. The indicators are used to measure the baseline at neighbourhood and city level. Through these indicators, this index is used to evaluate the extent of the interventions implemented to improve the sanitation service chain.

While the USSI is able to evaluate the sanitation status at a local level, it cannot supply data on the foundations of the problems it has uncovered (Hawkins and Muximpua 2015). To understand how to solve issues within sanitation, we need to be able to determine the origins of these issues. This is especially crucial within the sanitation sector, where it has been difficult to target the specific issues within infrastructure at all levels. Furthermore, we have also been able to learn useful lessons from how they have incorporated the Analytic Hierarchy Process (AHP) technique in analysing how indicators are ranked.

3.4.3. Faecal Contamination Index (FAECI)

The Faecal Contamination Index (FAECI) is composed of the three WASH components: water, sanitation and hygiene (Wolf, et al. 2019). These components are made up of several indicators including basic drinking water services, open defecation and basic handwashing facilities (Wolf, et al. 2019). A large FAECI score means a high estimated faecal contamination within the community. This study focused on areas where some WASH interventions have taken place and it outlined the importance of separating human excreta from human contact along the whole sanitation value-chain in order to prevent diarrhoeal disease (Wolf, et al. 2019).

The lack of data had played a role in the limitations of the FAECI. The FAECI cannot give a comprehensive account of potential pathways for faecal transmissions. Due to data
limitations, certain indicators such as on handwashing were not as thorough and alternative contamination pathways such as through food, soil and flies were not included. Nevertheless, it is important to remember that the FAECI illustrates a first attempt to evaluate the effects of faecal contamination at a community level. When designing our frameworks for calculating risk, we have been able to learn from the FAECI analysing faecal contamination from a community level.

3.5. The potential for sanitation risk indices

Sanitation risk indices could be hugely beneficial to the sanitation sector if implemented by sanitation organisations operating in the same geographical local. A new associated risk score could then be calculated to assess the potential risk reduction achieved by different sanitation related investments as part of a cost-benefit analysis.
4. Preparing data for our sanitation risk index

SRIs rely on the information that feed into them. In this chapter, we outline how we have prepared the data we have used in our SRIs, and the challenges we have faced with the quality of this data. We share this information as part of our commitment to being transparent about how we use geospatial data and how we recognise the current limitations of our analysis. This is important as part of our ongoing dialogue with users and stakeholders in order to build and maintain trust, and to work together to improve the quality of data that is available for future analysis.

4.1. The data we have used

In our previous report we identified several indicators and available open datasets that would be useful in creating a baseline to understand the state of sanitation provision. We advocated for the standardisation of these datasets so that they could be more easily included in analyses such as risk index calculations.

In this report we have identified a set of indicators to help us predict areas of high risk in the 5eme arrondissement of Antananarivo. We define a high-risk area as an area with a high probability of uncontained faecal waste in the environment. We have gathered open datasets for these indicators; these are described in appendix 1.

4.2. Normalising the data

We needed to normalise each dataset due to the vast differences in units and scale between the different indicators. To do this, we calibrated values of between 0 and 1 to each data point within the dataset, with 0 being low risk and 1 being high risk. For example, for the ‘households sharing toilets’ dataset, we assigned values of 0 to those households who did not share their toilet with any other households, and 1 to those households who rely solely on public toilets and therefore share with many other households. This is explained in more detail in appendix 1.

4.3. Data quality

One of the biggest challenges for improving data-driven decision-making in the sanitation sector is the availability of useful datasets. Working in data-poor environments and sectors means that often the only datasets available to us for some indicators are of low quality. They may, for example, be too old to adequately represent the current situation, be of low resolution, or be partial or incomplete. We have tried to minimise the effect of this on our analysis by working with the most recent datasets we can access for each indicator. We also decided to work only with datasets where at least 80% of the datapoints were present.

There is no agreed method on rating the quality of spatial datasets (de Bruin, 2011), so it was difficult for us to include or exclude a dataset based on its quality. We have had to balance...
utilising poor-quality datasets for important indicators (and increasing our resulting error margin) or not being able to include these important indicators.

Despite working to overcome these challenges, we are aware that potential errors in our models are largely due to the presence of null values in the datasets we used. In the future, we will also work to define the level of error we can work with where our analysis is still useful to our users. We will also investigate using sophisticated interpolation techniques to reduce our need to use poor quality data, and further hone the datasets that are critical to our analysis.

The outputs of the SRI in this report are still useful to demonstrate what can be created, and we will continue to work with stakeholders to improve the quality of the data. As we outlined in our previous report, standardised sanitation value chain data that is regularly updated and shared with the sanitation sector will greatly increase the quality of our analysis, and will reduce the need for repetitive surveys of sanitation provision within an area.
5. Designing our sanitation risk indices

Building on our research, we have designed three risk indices. These indices each combine the same set of 13 indicators in different ways to predict the level of risk of uncontained faecal waste in the environment in the 5ème arrondissement in Antananarivo (abbreviated to CUAS5). These indicators represent a range of elements that are crucial to predicting the level of sanitation risk: they describe environmental factors, those related to the sanitation value chain and social factors.

This chapter describes how, for each index, we inputted the datasets and produced risk calculations for our study area. We then visualised these risk calculations as maps, which we tested with our users; their feedback has led us to include the risk level shown both on a 30x30m grid, and also to class fokontanies (the smallest administrative division in Antananarivo) by the areas of highest risk within their boundaries. We discuss our validation process, and how we will continue to iterate the indices to improve its accuracy.

5.1. Sanitation risk index 1

The first index we developed simply adds together normalised values of the environmental indicators, social indicators and value chain indicators. Following Campos et al., we treat indicators that “define the physical, environmental and social conditions...as important predictors” of risk to communities (2015, 375). We then multiple these indicators by household density.

\[ SR1 = (\text{Risk}_{\text{Environment}} + \text{Risk}_{\text{Value chain}} + \text{Risk}_{\text{Social}}) \times \text{Household density} \]

We categorised each dataset as either an environmental risk, a sanitation value chain risk or a social one:

Table 1 - Grouping of datasets for SR1

<table>
<thead>
<tr>
<th>Environmental indicators</th>
<th>Sanitation value chain indicators</th>
<th>Social indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood risk</td>
<td>Households sharing toilet</td>
<td>Population density</td>
</tr>
<tr>
<td>Road density</td>
<td>Main drinking water source</td>
<td>Household density</td>
</tr>
<tr>
<td>Terrain movement</td>
<td>Toilet type</td>
<td>Children aged under 5 per household</td>
</tr>
<tr>
<td></td>
<td>Toilet location</td>
<td>Rent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tax</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Open defecation</td>
</tr>
</tbody>
</table>

These indicators were combined to give the following equation:
\[ SRI1 = (\text{Flood risk} + \text{Road density} + \text{Terrain movement} + \text{Households sharing toilet} \\
+ \text{Main drinking water source} + \text{Toilet type} + \text{Toilet location} \\
+ \text{Population density} + \text{Children aged under 5 per household} + \text{Rent} + \text{Tax} \\
+ \text{Open defecation}) \times \text{Household density} \]

It considers household density to be of equal importance to all the other indicators combined. This is to account for the additional risk that high household density poses in areas where sanitation facilities are poor (Hathi, et al. 2017).

We then visualised the index. Each visualisation uses a grading with five classes; each class contains an equal number of grid squares. When visualised, SRI1 gives the following maps:

![Figure 3. Visualisation of analysis produced from SRI1 for CUA5](image)

This index predicts a high level of uncontained faecal waste in the southwest, with another hotspot in the northwest of the study area. The northeast and east are generally predicted to have a low level of risk. This index generates values with few areas that have a significantly higher or lower risk than the others.

5.2. Sanitation risk index 2

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Our second risk index draws on literature from disaster risk management, as discussed in chapter 3.

\[
\text{SRI2} = \text{Average (Hazard + Exposure + Vulnerability)}
\]

To produce this index, we categorised each indicator as either hazard, exposure or vulnerability.

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Exposure</th>
<th>Vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood risk</td>
<td>Households sharing toilet</td>
<td>Children under the age of 5</td>
</tr>
<tr>
<td>Road density</td>
<td>Main drinking water source</td>
<td>Rent</td>
</tr>
<tr>
<td>Terrain movement</td>
<td>Toilet type</td>
<td>Tax</td>
</tr>
<tr>
<td>Open defecation</td>
<td>Population density</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Household density</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toilet location</td>
<td></td>
</tr>
</tbody>
</table>

We then added replaced our indicators with the blueprint formula to produce a value for each grid square:

\[
\text{SRI2} = \text{average (Flood risk + Road density + Terrain movement + Open defecation} \\
+ \text{Households sharing toilet + Main drinking water source + Toilet type} \\
+ \text{Population density + Household density + Toilet location} \\
+ \text{Children aged under 5 per household + Rent + Tax)}
\]
In contrast to the first index, all the indicators are assumed to be of equal importance to one another. When visualised, this index gives the following maps:

![Maps showing sanitation risk index 2](image)

**Figure 4. Visualisations of analysis produced from SRI2 for CUA5**

We see a much greater spread in areas that are predicted to have lower rates of uncontained faecal matter in the environment. Areas of high risk are largely located in the northeast and west of the study area, whereas the southeast is predicted to be at lower risk. Similar to SRI1, this index is limited by the assumption that all of the indicators are of equal importance to one another, limiting its accuracy. To improve this, we need to be able to weight each indicator according to its importance.

### 5.3. Sanitation risk index 3

For the third index, we utilised the Analytical Hierarchy Process method to develop weights for each indicator. We wanted to weight each indicator according to how important it was in predicting the level of uncontained faecal waste in the environment.

The AHP method is a rigorous method frequently used in geospatial analysis (Chandio, et al. 2013). It is a decision-making approach that allows users to individually evaluate the relative importance of an indicator compared to several other indicators (Yalcin 2008). It involves asking a variety of experts to evaluate the relative importance of multiple indicators that all contribute to one outcome (Kayastha, Dhital and De Smedt 2013).
The AHP method is used to produce weightings for each indicator:

\[ SRI3 = (l_1 W_{AHP}) + (l_2 W_{AHP}) + \ldots \ldots + (l_n W_{AHP}) \]

where \( I \) is the indicator and \( W \) is the weighting.

We asked a variety of experts to complete the AHP process to help us identify the relative importance of each indicator. Each expert was asked to consider each indicator in comparison to one another, and give it a rating of between 1 and 9 based on how important it was in predicting the level of uncontained faecal waste in the environment. If they considered an indicator to be much less important than another, it was given a rating of 1; if it was much more important, they would rate it 9.

![Figure 5. Rating scale used by experts when assessing relative importance of indicators for AHP method](image)

Their ratings were compiled into a table:

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Road density</th>
<th>Terrain movement</th>
<th>Sharing toilet</th>
<th>Drinking water source</th>
<th>Toilet type</th>
<th>Toilet location</th>
<th>Population density</th>
<th>Household density</th>
<th>Children under 5</th>
<th>Rent</th>
<th>Tax</th>
<th>Open defection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding</td>
<td>1.00</td>
<td>7.00</td>
<td>3.00</td>
<td>5.00</td>
<td>3.00</td>
<td>1.00</td>
<td>5.00</td>
<td>7.00</td>
<td>3.00</td>
<td>5.00</td>
<td>9.00</td>
<td>9.00</td>
</tr>
<tr>
<td>Road density</td>
<td>7.00</td>
<td>3.00</td>
<td>1.00</td>
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<td>3.00</td>
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<tr>
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<td>1.00</td>
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<tr>
<td>Household density</td>
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<td>Tax</td>
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<tr>
<td>Open defection</td>
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</tr>
</tbody>
</table>

![Figure 6. AHP table completed by an expert](image)

We then summed the values for each expert’s assessment of each indicator, and produced an average value for each indicator from all the completed tables. We normalised these average values between 0 and 1, giving a weighting for each indicator.

This produced the following equation:

\[ SRI3 = (\text{Flood risk} \times 0.17 + \text{Terrain Movement} \times 0.17 + \text{Road density} \times 0.12 + \text{Household density} \times 0.10 + \text{Population density} \times 0.10 + \text{Rent} \times 0.08 + \text{Tax} \times 0.07 + \text{Main drinking water source} \times 0.04 + \text{Children aged under 5 per household} \times 0.04 + \text{Open Defecation} \times 0.04 + \text{Households sharing toilet} \times 0.03 + \text{Toilet type} \times 0.02 + \text{Toilet location} \times 0.02) \]
It is clear from the weightings that the experts we consulted viewed environmental indicators - flood risk and terrain movement - as the key indicators that predict the level of uncontained faecal waste in the environment.

When visualised, this index produces the following maps:

![Maps showing risk analysis](image)

*Figure 7. Visualisations of analysis produced from SRI3 for CUA5*

This index shows hotspots in the northeast and northwest, and areas of low risk in the east. It correlates closely to flood risk dataset, as this was the indicator that was most influential by the experts and therefore has the highest weighting. This index gives the most even spread of values across all risk values.

The AHP method allows a far more nuanced prediction of risk than either of the first two indices. A key consideration when undertaking the AHP method is that it requires a clear and consistent explanation of each indicator; each expert needs to understand precisely what the indicator describes when considering how that indicator should be weighted. When adding input from additional experts, it is critical to maintain this consistency. This is something we will need to build into our future work with the AHP method.
5.4. Comparing indices

The three indices we have outlined above all use different formulae and produce slightly different predictions of the areas of highest and lowest risk. All three predict areas of high risk in the north of CUA5, particularly in the fokontany of Alarobia. All of the indices closely follow the levels of open defecation across the study area; this implies that we should examine levels of correlation between this dataset and the others we have used within the indices to ensure they are each bringing new information to our research.

While there is consistency in the prediction of the high risk areas, there is inconsistency in the prediction of the low risk areas. We hypothesise that this has been caused by our focus on identifying higher risk areas and our priority to categorise factors that contribute to higher risk. Further investigation would be needed to refine the identification of lower risk areas.

5.5. Validation

There is no dataset that shows the level of uncontained faecal waste in the environment in CUA5. In lieu of this dataset, we asked experts from several sanitation providers working in Antananarivo for their perception of the level of sanitation risk across our study area. We asked them to highlight the areas of highest and lowest risk in CUA5 on perception maps. Below is a screenshot of the exercise:

![Map showing areas with high and low sanitation risk](image)

*Figure 8. Validation exercise completed by experts to highlight areas of highest and lowest sanitation risk in CUA5*

---

1 It was important to utilise the expertise of a different group of people than the group that helped with the AHP method for SRI3. If we had used the same group of people for both the AHP method and the validation process then we could incorrectly identify SRI3 as the strongest performing index.
We need to continue asking local experts to complete these validation exercises so that we are able to assess the validity of each index. Once we have a sufficient number, we will combine them into one master perception map. We will then use two methods in combination to assess the indices:

- Quantitative comparison: we will rank each area on the map by risk level and take the top and bottom 10%. We will compare the locations of these areas to those highlighted on the master perception map.
- Statistical comparison: we will use a statistical methodology to compare each index to the master perception map and show which index produces results that are most similar to the perception map.

It is important that we use both of these methods in combination. The statistical method compares the values of each pixel, but doesn’t include a spatial element; the quantitative method does include the spatial component. Combining the two enables us to properly validate the performance of the index.

5.6. Developing the sanitation risk index

After publishing of this report, we will continue to test and develop our sanitation risk index. To do this we will:

- Continue to work with local stakeholders and experts to complete more perception maps to support our validation process. This will allow us to better understand the indicators influencing the level of sanitation risk, which only then enables us to evaluate and refine our index.
- Continue to work with local stakeholders to ensure that the index meets their needs and informs their decision-making process.
- Continue to learn from the data survey used in the World Bank’s survey Measuring Urban Living Standards in Antananarivo, 2016 (World Bank 2017).
- Improve our risk formulae with the best available inputs. In particular, we will:
  - Continue to work with stakeholders to collect and share higher quality datasets that can be used for analysis.
  - Continue to investigate alternative datasets and sources and work with local stakeholders to improve the quality of the insight we can produce. For example, in this report we have used flood risk data from GeoNode as it is openly accessible. We want to test using regularly updated data from Google Earth Engine. We would then need to test both datasets with control data before deciding which one to incorporate into our analysis. With some datasets, we will need to strike a balance between a finer level of detail and regularly updated data.
  - Continue to explore proxy data sets. For example, Bruderle and Hodler (2018) suggest that night-time satellite imagery of night lighting can serve as a proxy for GDP.
• Investigate alternative ways to overcome the effects of working in a data poor environment. We will explore ways that we can incorporate probability modelling. For example, maximum entropy modelling techniques would enable us to use datasets from small but intensively sampled areas to make predictions about other similar areas. This would be useful for indicators like open defecation: existing available datasets are of low quality, but the experts we have consulted when constructing SRI3 emphasised its importance to our analysis, so we don’t want to exclude it from our analysis.
• Continue to explore how we can most effectively communicate and moderate the impact of data quality on our analysis.
• Explore ways that we can make our source code open so that other organisations can collaborate with us in refining and maintaining our analysis.

5.7. Developing the visualisations

We are publishing the results of our indices as maps. To improve these visualisations, we will:

• Continue to work with local stakeholders to ensure that the visualisations are easy to navigate, understand and use to inform action.
• Continue to explore ways to make the visualisations accessible to disabled people. For example, we have designed our maps so that they are accessible to users with colour blindness, but we want to do much more to make our insight usable and useful.
6. Building our sanitation data platform

We want to ensure that the insight we produce is useful and accessible to decision-makers. To enable users to access, interact with and feedback on our work, we are hosting the visualisations on an online platform. This is our sanitation data platform (SDP).

We have built this platform in Shiny. Shiny allows users to build standalone interactive apps on webpages using the R analysis software. It is interactive, free and easy to use for teams like ours without dedicated web developers.

6.1. Current functionality

We are still building, testing and developing the SDP. Currently it has three tabs. The first introduces the SDP, explains the scope of the analysis it hosts and invites users to provide feedback.

![Sanitation Data Platform: Geospatial Visualisations for three Sanitation Risk Indices for Antananarivo, Madagascar](image)

*Figure 9. Screenshot of the sanitation data platform’s homepage*

The next three tabs shows the visualisations of each sanitation risk index with the maximum risk level for each fokontany. Each tab includes a description of the risk index and a summary of what the visualisation shows. The visualisations are interactive, and users can: zoom in and out; pan the map, click on individual fokontanies to see their name, risk score and rank compared to other fokontanies in CUAS; switch between fokontany-level view and 30x30m grid; and see areas with high or low risk levels. The base map can be toggled between street map and satellite view, and users can overlay transport routes within CUAS to allow them to more easily identify locations and use the SDP for planning.
Figure 10. Screenshot of SRII analysis at fokontany view

Figure 11: Screenshot of SRII analysis at fokontany level with satellite imagery
Figure 12. Screenshot of SRII analysis at fokontany level and grid level

Figure 13. Screenshot of SRII analysis at fokontany level and grid level with road network
The final tab shows the raw data we have used in producing the analysis, including links to the original sources of the data to enable users to download the data we used and test or replicate our analysis. Our current analysis only uses open datasets, when we incorporate datasets from sanitation providers it is possible that these providers will not want their data to be fully open for commercial reasons, but we will seek to remain as open as we can.
6.2. Future development

We tested the sanitation data platform with Gael Fetranaina Raserijaona, an urban specialist at the World Bank. He gave us detailed and useful feedback which we are working to incorporate into the design of the SDP beyond the lifetime of this project. In particular, we will be:

- Keeping the design clean and simple;
- Translating the sanitation data platform into French;
- Continue to improve colour scheme to emphasise areas of low risk as well as high;
- Continue to expand on our explanation of what each risk level means;
- Including an infrastructure layer to aid user location recognition and the planning of routes for the transport of faecal waste;
- Enabling printing and offline access of the visualisations for policy makers;
- Considering how we can facilitate and encourage citizen engagement with the platform.

We will be sharing the code on GitHub for the SDP with the World Bank Data Innovation Fund team so that they can develop their own tool from the code.

6.3. Opportunities for decision-makers

Our insight needs to be useful and accessible for decision-makers through the sanitation data platform. Going forward, we will:
• Work with other stakeholders and decision-makers in Antananarivo to explore how to improve the tool’s functionality and interactivity, with a focus on honing the data that decision-makers need and automating data sharing;
• Explore how the tool can be scaled for the rest of Antananarivo and then expand into other emerging cities.
7. Next steps

This project has been a crucial step towards our goal of enabling decision makers to use data to improve sanitation for vulnerable communities. As part of this project, we have produced three reports so far, using the 5eme arrondissement in Antananarivo, Madagascar as their study area:

- The sanitation data gap in Antananarivo, Madagascar - assessment of the sanitation data gap for Antananarivo to highlight the need for more good quality data on the sanitation value chain;
- Recommendations for the design of a new data standard for sanitation data - a data standard to provide guidance for when new data collection surveys are designed, or existing data is prepared for sharing;
- Recommendations for a new sanitation risk index and geospatial visualisations to aide decision making in Antananarivo, Madagascar - designed a new sanitation risk index and sanitation data platform so that decision makers can access geospatial analysis from the data that is currently available.

We will continue to build on the work we have done as part of this project, improving our analysis and making our work useful and accessible. We will particularly focus on collaborating with local stakeholders, decision makers and experts in Antananarivo to develop our sanitation risk indices, visualisations and sanitation data platform. We plan to take these steps as part of our UK Aid Direct-funded project to launch a Sanitation Data Hub in Antananarivo. This project will allow for continued stakeholder engagement, data collection and the refining of the standard, index and platform.
8. Appendix 1: data sources

We used several different open datasets in our analysis; all of these are accessible to others wanting to replicate or test our analysis. After accessing each dataset, we first clipped it to our study area, using administrative boundary data (see table). We then pre-processed each dataset, normalising it to assign values of between 0 (low risk) and 1 (high risk) to each data point. The pre-processing we went through for each dataset is explained below.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Year</th>
<th>Source</th>
<th>Data pre-processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative boundaries</td>
<td>2015</td>
<td>Commune Urbaine d’Antananarivo Accessed through: Resilience Madagascar</td>
<td>We used this dataset to clip all the other datasets to our study areas.</td>
</tr>
<tr>
<td>Flood risk</td>
<td>2020</td>
<td>Cellule de Prévention et Gestion des Urgences Accessed through: Resilience Madagascar</td>
<td>The original file was in French, so we first translated it into English. We classified areas which flooded often as high risk, and those which are not flooded often as low risk.</td>
</tr>
<tr>
<td>Terrain movement</td>
<td>2015</td>
<td>Habaka NGO Accessed through: Resilience Madagascar</td>
<td>The original file was in French, so we first translated it into English. We classified areas with strong terrain movement as high risk, and those with weak terrain movement as low risk.</td>
</tr>
<tr>
<td>Road density</td>
<td></td>
<td>Overpass Turbo</td>
<td>We measured the total length of roads within each grid square. Squares with high amounts of road length were considered to be more accessible to pit emptying and toilet maintenance services, so were classed as low risk. Squares with low values for road length were classed as high risk.</td>
</tr>
<tr>
<td>Population density</td>
<td>2018</td>
<td>Facebook Connectivity Lab and Center for International Earth Science</td>
<td>We classified areas with high population density as high risk, and those with low population density as low risk. The dataset didn’t require any other pre-processing.</td>
</tr>
<tr>
<td>Number of children aged under 5 per household</td>
<td>2018</td>
<td>Information Network</td>
<td>We classified areas with high numbers of children aged under 5 per household as high risk, and those with low numbers as low risk. The dataset didn’t require any other pre-processing.</td>
</tr>
<tr>
<td>Household density</td>
<td>2020</td>
<td>Gather created this dataset using imagery from Google Maps.</td>
<td>In creating this dataset, we assumed a density of one household per rooftop. We acknowledge the limitation of this assumption: multiple households may live under one roof; a building may have several households and therefore house several families; some of the rooftops may not be for residential buildings. We want to develop the sophistication of our analysis for this dataset.</td>
</tr>
<tr>
<td>Open defecation</td>
<td>2016</td>
<td>Antananarivo Urban Poverty and Resilience study</td>
<td>s8_hsgtlt We created this dataset from a question asking what type of toilet the household uses. We created a binary indicator by classifying results of ‘none, do it anywhere’ as open defecation and therefore high risk; everything else we classified as low risk. The remaining answers from the dataset were included as part of the ‘toilet interface’ indicator.</td>
</tr>
<tr>
<td>Toilet type</td>
<td></td>
<td></td>
<td>s8_hsgtlt When normalising these values, we gave toilet type a rating of 0.33, 0.66 or 0.99 based on the level of risk they pose to the user. Those listed as ‘toilet with a seat (with or without flush)’ or ‘toilet without seat (with or without flush)’ were given a value of 0.33. Those described as ‘latrine slab in wood or mud’, ‘toilet slab in concrete (cement) or porcelain or glassfiber’ were given a value of 0.66. Those described as ‘simple hole’ were given a value 0.99 and classed as highest risk.</td>
</tr>
<tr>
<td>Households sharing toilet</td>
<td></td>
<td></td>
<td>s8_hsgtns This indicator describes the number of households that share each toilet. In the raw data, this is a numerical value ranging from 0-88. When normalising the data, we classified 0 as low risk and 88 as high risk.</td>
</tr>
</tbody>
</table>
| **Main drinking water source** | s8_hsgwtr  
This question looked at the main source of drinking water for each household. When normalising these values, we gave responses a rating of between 0.25 and 1. Those listed as 'private tap in the courtyard' or 'tap inside dwelling' were given a value of 0.25. Those listed as 'public tap/water vendor' or 'shared tap in courtyard' were given a value of 0.5. Those listed as 'protected or covered spring', 'uncovered well without a pump', 'covered well without a pump' or 'well equipped well with a human powered pump' were given a value of 0.75. Those listed as 'rainwater', 'surface water' or 'unprotected spring' were given a value of 1. |
| **Rent** | s8_hsgrent1  
This is a numeric value ranging from 0-2,300,000 in the raw data, representing the amount of rent paid each month in MGA. We classed those paying 0 rent as high risk, and those paying 2,300,000 as low risk. We combined this with tax mean and used it as a proxy for GDP. |
| **Tax** | s8_hsgmtp  
This is a numeric value ranging from 0-1,500,000 representing the amount of tax paid each month in MGA. We classed those paying 1,500,000 as low risk and those paying 0 tax as high risk. We combined this with rent mean and used it as a proxy for GDP. |
| **Toilet location (inside or outside)** | s8_hsgtll  
This question asked whether the household's toilet was inside or outside their dwelling. It is a binary indicator in the raw data. We classified toilets outside the dwelling as high risk, and those inside as low risk. |
## 9. Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contamination</td>
<td>When faecal matter comes into contact with drinking water and surface level water.</td>
</tr>
<tr>
<td>Dataset</td>
<td>The output of a survey designed to collect information on a particular indicator or indicators.</td>
</tr>
<tr>
<td>Exposure</td>
<td>The type and depth of contact between the hazard and individuals within local communities. The intensity of the exposure depends on the pathogen concentration within the waste, the type of contact and the duration of exposure.</td>
</tr>
<tr>
<td>Fokontany</td>
<td>“Village”, the smallest territorial subdivision in Antananarivo.</td>
</tr>
<tr>
<td>Hazard</td>
<td>In relation to sanitation, hazard refers to faecal waste. Outside of sanitation, it usually refers to a natural phenomenon such as flooding and earthquakes.</td>
</tr>
<tr>
<td>Indicator</td>
<td>Quantifiable characteristics of a population or area.</td>
</tr>
<tr>
<td>Risk (sanitation)</td>
<td>Risk refers to an individual’s likelihood of coming into contact with faecal waste.</td>
</tr>
<tr>
<td>Sanitation Data Platform</td>
<td>Online platform that hosts geospatial visualisations of the Sanitation Risk Index. The sanitation data platform will be developed to allow for automated data sharing.</td>
</tr>
<tr>
<td>Sanitation Risk Index</td>
<td>A Sanitation Risk Index (SRI) is a numerical calculation that represents the severity of the sanitation risk. It is a combination of vulnerability, exposure and hazard.</td>
</tr>
<tr>
<td>Sanitation Value Chain</td>
<td>This is a term used to categorise infrastructure and services—containment, emptying, transport, treatment and disposal or reuse.</td>
</tr>
<tr>
<td>Transport</td>
<td>The physical movement of sludge from the storage device to where it is either discarded or treated.</td>
</tr>
<tr>
<td>Vulnerability</td>
<td>This refers to the individual’s susceptibility to contracting the disease and the effect the disease has on a person’s health.</td>
</tr>
</tbody>
</table>
10. Acknowledgements

This project, **Assessing the accessibility of urban sanitation data in Antananarivo, Madagascar**, submitted in response to the 2018 call for proposals by the World Bank’s Development Data Group (DECDG) and the Global Partnership for Sustainable Development Data (GPSDD), is supported by the World Bank’s Trust Fund for Statistical Capacity Building III (TFSCB-III) with financing from the United Kingdom’s Foreign, Commonwealth and Development Office, the Department of Foreign Affairs and Trade of Ireland, and the Governments of Canada and Korea.
11. About Gather

Gather’s mission is to close the sanitation data gap, so that decision-makers know how and where to improve sanitation infrastructure and services. In doing so, we will help improve access to safely-managed sanitation for five million people in four emerging cities around the world by 2025.

In 2020 Gather was recognised by Digital Leaders as one of the top 10 tech for good initiatives in the UK. In 2019 Gather’s portfolio of work won second place out of 3,100 global entries in the World Bank’s Ideas for Action. In 2018 Gather was recognised by Forbes, MIT Technology Review and Tech4Good.

Gather’s team are: Raheema Abdirizaq, John Peter Archer, Indigo Brownhall, Lindsey Noakes, Nicolas Radanielina and Lieven B Slenders.

We would like to give special thanks to Josh Wilson who helped us with the research and design of the sanitation index and Roshan Gulati who helped with initial mapping.

For more information, please visit www.gatherhub.org
12. Bibliography


