Comparing methodologies to calculate UNICEF's Children's Climate Risk Index (CCRI)

Feasibility Study

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1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) in the 2023 Synthesis Report of its 6^{th} Assessment Report [1] states '*widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred*' due to human activity. Additionally they point out that '*vulnerable communities who have historically contributed the least to current climate change are disproportionately affected*'. This makes it a matter of urgence (alongside measures to reduce human activities that are harmful to the climate) to gather and report on data that shows the vulnerability of communities and countries, in order to inform policy and direct support where it is most needed.

In any community, and for many different types of hazard, children are often the most vulnerable group. The United Nations Children's Fund (UNICEF), established by the United Nations in 1946 to meet the needs of children worldwide, reported in 2021 on how the climate crisis impacts children everywhere [2]. They gathered data on 20 different indicators, covering climate hazards such as Water scarcity, heatwaves, flooding and air pollution, as well as socioeconomic data representing the resilience of communities, such as education levels, poverty, Social Protection and Nutrition.

UNICEF combined these indicators using the INFORM Climate change risk index methodology [3] to create the Children's Climate Risk Index (CCRI). The CCRI not only ranks countries according to their children's relative overall vulnerability, but also shows separately the severity of hazards they face, and the ability of each country to withstand and recover from those hazards.

In this Feasibility study we examine the dataset and methodology that was used to build the CCRI, and compare it with an alternative method of index calculation, using the same data. We also note that only 163 of the 193 member states of the United Nations appear in the CCRI, and consider ways that representation could be increased.

2 Background and Literature Review

Before commencing a detailed analysis it is important to define the terms that we will use. Unfortunately there seems to be limited agreement on the precise definitions of concepts such as Hazard, Risk, Mitigation, Vulnerability, Adaptive Capacity, Sensitivity and Exposure.

For example, Hofste et al in a Technical Note for the World Resources Institute looking specifically at water risk [4] define the equation

$$Risk = Hazard \times Exposure \times Vulnerability$$

where Hazard is a threatening event or condition, Exposure is the people or assets affected, and Vulnerability is their resilience (or lack thereof).

However Marshall et al [5] define Vulnerability as the combination of Exposure and Sensitivity, ameliorated by Adaptive Capacity, where Exposure represents the hazardous climate events, Sensitivity is the amount to which social or ecological systems can tolerate that Exposure, and Adaptive Capacity is the ability of the affected system to respond.

Clearly it will be necessary to investigate and understand these conflicting definitions, to clarify how the terms will be used here. Brooks [6] provides a detailed discussion of this problem, in which separating out definitions of biophysical and social vulnerability is helpful in resolving contradictions.

Looking specifically at environmental hazards, Cutter [7] presents a broad definition of Vulnerability as ‘a potential for loss’ but in attempting to narrow that down, she is able to list 18 different definitions from publications spanning the years 1980 – 1995. More recently, Biswas 2023 [8] provides an up to date literature review of the concept of socioeconomic vulnerability, across different disciplines.

While it is relatively easy to measure physical hazards numerically (eg. temperature, duration, flood level, frequency), and the number of people affected can be estimated using gridded population data [9], it is harder to assign numerical values to the quality of governance of a country, or even to identify the factors that contribute to the vulnerability of its population.

Many studies of environmental hazard and vulnerability attempt to quantify the resulting risk by calculating an index. Reckien [10] considers methods of index construction for social vulnerability due to climate events in New York City, noting that the construction method, choice and weighting of data can all influence the index values arrived at. She looks chiefly at two types of index: the ‘variable addition’ and the ‘variable reduction’ models. In the variable addition approach, the data variables are chosen for their high likelihood of being significant to the problem at hand, followed by normalisation and addition to create the index figure. Contrastingly, the variable reduction approach gathers a large number of data variables that *may* be significant, and then applies a technique such as PCA to reduce the number of variables to their underlying factors, which can be similarly normalised and added.

Another finding Reckien [10] draws attention to is the difference between choosing input data variables that are area-based (number of people/km^2) and those that are population-based (eg. percentage living in poverty in the relevant area), with the former found to be more robust under different models. Fortunately the UNICEF dataset uses area-based data, mapping population to countries to calculate their climate risk.

There are already several established indices that attempt to quantify environmental risks for individual countries (see Box for two examples), so why did UNICEF feel the need to create another one?

- Since 2013 the University of Notre Dame has hosted the Notre Dame Global Adaptation Initiative (ND-GAIN). Their ND-GAIN Country Index is based on 45 indicators including one to measure business investment [11]. It is calculated as the scaled difference between a country’s Readiness and Vulnerability, and shows 181 countries in 2023 data [12].
- The World Risk Index [13] is a statistical model which combines data on extreme natural events with socioeconomic data to assess how vulnerable each country is to these hazards. Updated annually and considering all hazardous events (eg earthquakes), not just those attributable to climate change, the 2020 edition includes 181 countries. The index is defined as the product of Exposure and Vulnerability, shown on a 0–100 scale.

The answer must be in UNICEF’s specific focus on children. There are several reasons why children are more vulnerable to climate-related events than adults [2] (p11). These include their physical vulnerability to climate events such as heatwaves and drought; their greater physiological weakness when exposed to lead pollution and other environmental toxins; and their lower survival rate from climate-exacerbated diseases like malaria. Perhaps most significantly, children whose health or education is impacted by climate-related deprivation may carry this disadvantage throughout their whole lives.

Their lack of agency is highlighted by O'Brien 2008 [14] who states that children's capacity to contribute to risk reduction and adaptation has been largely overlooked - children's participation in decision-making is likely to only become more important as the effects of climate change increase.

To calculate the CCRI, UNICEF chose the Index for Risk Management (INFORM), whose concept and methodology were first published by the European Commission in 2014 in a report by De Groeve et al [15]. The establishment of this index came about through the desire for a common evidence base for global risk analysis to support proactive crisis management, from partners including UN agencies, non-governmental organisations and research institutions. Marzi et al [3] report that INFORM is calculated from data encompassing Hazards, Exposure, Vulnerability and Lack of Coping Capacity, and can be used with future projections as well as current data. Returning to Reckien's classification of indices above [10], INFORM is a 'variable addition' index.

Marzi et al commend the INFORM methodology for its *'comprehensive framework, use of open data and transparent methodology'* [3] although the complexity of the calculations involved (a combination of arithmetic and geometric means) does detract from its transparency. An additional source of complexity in the INFORM calculation is the way that population data is combined with the indicators at various stages in the method, which could have lead to distortions in the results.

The INFORM methodology has been adapted for different studies and situations. In the form that UNICEF use it [2], they define two pillars, where Pillar 1, the Hazard domain, quantifies the climate-related risks that children face; and Pillar 2, the Social Vulnerability domain, describes the capacity of their country to mitigate those risks. Together these components are combined into a single index, by which countries can be ranked.

As a comparison with INFORM, we will use an alternative methodology to calculate a children's climate risk index using the same data. The methodology chosen is the University of South Carolina's Social Vulnerability Index (SoVI) [16] which was set out in 2003 by Cutter et al [17], with significant updates in 2010–2014 and 2019. For more technical details, see Section 2.1.1 below.

In contrast to INFORM, the SoVI index is a 'variable reduction' model, which indicates that the comparison will be informative, whatever the result.

2.1 Methods and techniques

To work with this dataset we will need to make use of the following methods and techniques.

2.1.1 SoVI Social Vulnerability Index

The SoVI method is set out in a 'recipe', available online [18]. The process followed is a principal components analysis (PCA) on normalised standardised input variables, taken mainly from the US Census Bureau in the case illustrated. For example, these variables include percentages of different ethnicities, median housing value, per capita income, percent unemployed; 29 variables in all.

The next step in the recipe is extraction of factors, which are named according to the variables that have most contributed to them. These factors are inspected and given a sign +/- depending on whether they increase or decrease vulnerability. These are then summed to create an overall score, which can be mapped to high/medium/low classes using bands of standard deviations from the mean, and visualised on a geographic map.

2.1.2 Methods of data imputation

As will be observed in Section 3.1 below, there are missing values in the CCRI dataset.

One feature of the PCA methodology is that it is unable to work with a dataset which has missing values. Since many real world datasets do contain missing values, correspondingly many ways have been utilised to resolve this problem. These include dropping rows with missing values, replacing the missing values with an estimated value (which could be a mean or median of this column, or a value chosen at random from another row), or more computational techniques using regression or expectation-maximisation to generate plausible values. In general, it will be necessary to study the reason why a value is missing, to decide on the best technique to work with it. There may be different answers to this question, depending on the indicator we are looking at.

2.1.3 PCA techniques with missing data

An alternative to a data imputation approach is to use an algorithm for PCA that handles missing values internally. One such is MacroPCA developed by Hubert et al [19], which is a combined approach that deals robustly with missing values, and at the same time can identify atypical rows (rowwise outliers) and atypical values in individual cells (cellwise outliers). It is intended that different techniques to handle missing values will be investigated as part of this study. For further details see Section 3.2.

3 Preliminary Investigations and Findings

3.1 The CCRI dataset

The data on which UNICEF's CCRI index was based includes 203 countries, although only 163 appear in the published report. Some of those absent were omitted due to missing or unreliable data; this particularly affects small island states under 20k km^2 because a geographic dataset with a coarse resolution will not identify them. There is also a lot of variability between countries in terms of what data is published, with less developed countries having fewer resources to devote to this.

A box and whisker plot was generated to investigate the distribution of the different variables (indicators) in the dataset, see Figure 1. We can already see from this that some indicators may be problematic;

- Coastal Floods and Tropical Cyclones both have a large range and a median of zero, presumably due to the number of countries that are not on the coast, or situated in the Tropics, respectively.

- Temperature Anomaly is skewed to the right; WASH is skewed to the left
- Governance and Climate Shocks have small ranges so may provide less differentiation

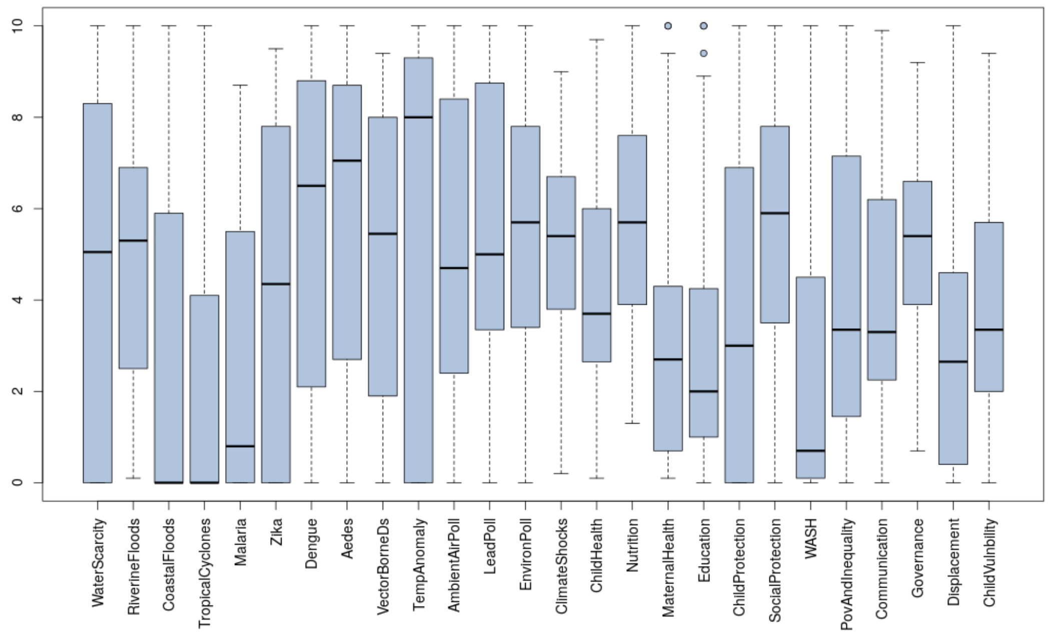


Figure 1: Distribution of the indicator data used to calculate the CCRI index (see Section 3.1).

It is also notable that there is significant correlation between the indicators, see Figure 2. This suggests a variable reduction technique such as PCA may be a promising analysis tool, as it is able to identify the (fewer) underlying factors that give rise to the observed data.

Some indicators (eg. Water scarcity, Malaria, Child vulnerability) in the dataset do not have any missing values. Others have many; the indicators with the most missing values are shown in Table 1.

3.2 Investigation of techniques

Given a dataset with missing values, and an intention to use a method (PCA) that cannot handle missing values, it will be necessary to decide on a technique to resolve this situation. In the first place, simplistic techniques will be used, such as replacing the missing values with global or regional means, see Table 2. In this table we can see that in some cases the mean and median are very similiar (eg. global, Polynesian Nutrition), indicating a symmetric distribution, but for other indicators they can be very different (eg. global WASH, Polynesian Social Protection). Note also that the Polynesian averages are based on very little data - in one case only a single record. However to obtain initial results this approach should be adequate.

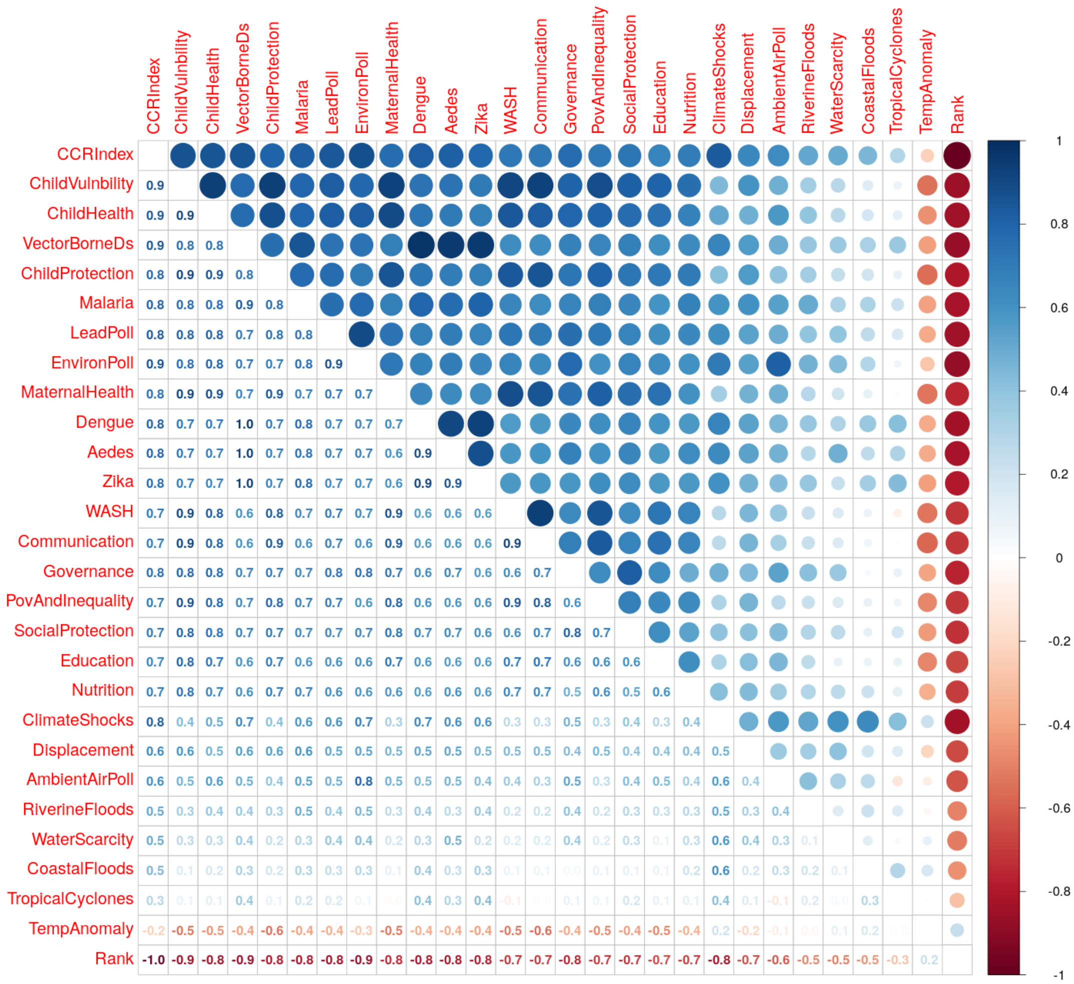


Figure 2: Correlation between indicators used to calculate UNICEF's CCRI index using the INFORM methodology (see Section 3.1).

4 Project Proposal

The research question is: What can we learn from a comparison of different methodologies to calculate UNICEF's Children's Climate Risk Index?

Phrased as a hypothesis, the question could be written:

> Different methods of construction of indices to represent social vulnerability due to climate risks will give very similar results, indicating that the choice of index is of limited significance.

To investigate the truth of this hypothesis, we will consider what makes a good index, and how best to compare different ones, giving particular attention to countries with limited data. The SoVI methodology will be applied to the same dataset used by UNICEF to create the CCRI using the INFORM methodology, and the results compared using the methods decided on above.

If time allows, the following extensions can be considered:

- Exploring additional data sources, particularly in relation to countries that are missing from the published INFORM index
- Focusing on one or two indicators where the methodology used in INFORM is complicated or unclear, and comparing the data directly
- Comparing a third index with the two considered here
- Dropping some indicators to consider how the SoVI index changes, and whether this brings in any missing countries
- Possibly recalculating the INFORM index with either more data or fewer indicators (depends on an R script written by another student being available).

4.1 Success Criteria

To be considered successful, this project will need to extend our understanding of social vulnerability indices, when used to measure the relative risk of children worldwide to climate change. By using different methodology (variable addition/variable reduction) to calculate the index, on an identical dataset, the results may be very similiar, or potentially significantly different. If the resulting indices are very similar, that would indicate that both methods are similarly appropriate to the task. Whereas finding differences (which could be between related countries or regions, or seemingly randomly distributed) would present further research questions to answer.

Indicator	No. of missing values
Child Protection	71
Nutrition	35
Social Protection	33
Education	11
Poverty and Inequality	10
Maternal Health	9
Governance	9
Lead Pollution	7
Child Health	7
WASH	4
Communication	3

Table 1: CCRI indicators that have missing values in the UNICEF dataset (see Section 3.1).

Region	Indicator	Mean	Median	Count
global	LeadPoll	5.59	5	202
global	ChildHealth	4.18	3.7	202
global	Nutrition	5.82	5.7	202
global	MaternalHealth	3.05	2.7	202
global	Education	2.79	2	202
global	ChildProtection	3.78	3	202
global	SocialProtection	5.54	5.9	202
global	WASH	2.53	0.7	202
global	PovAndInequality	4.20	3.35	202
global	Communication	4.29	3.3	202
global	Governance	5.18	5.4	202
Polynesia	ChildHealth	3.26	3.3	5
Polynesia	Nutrition	1.30	1.3	1
Polynesia	MaternalHealth	3.52	3.4	4
Polynesia	Education	2.52	1.3	4
Polynesia	ChildProtection	6.40	6.4	1
Polynesia	SocialProtection	6.63	9.9	3
Polynesia	PovAndInequality	4.14	5	5
Polynesia	Communication	3.50	4.6	5
Polynesia	Governance	4.80	5.2	3

Table 2: Average values (mean, median) calculated for indicators with missing values, for the global dataset and an example region. The number of values that contributed to each average is also shown (see Section 3.2).

5 Workplan

To answer the research question, a number of tasks have been identified, which are set out below. By documenting their dependencies it was possible to arrive at a core project, and several additional analyses that could be performed if time permitted. The dependency diagram in Figure 3 shows how the core tasks depend on each other.

Time estimates for tasks in the core project were made, and are shown on the Gantt chart in Appendix A. Task numbering is maintained throughout.

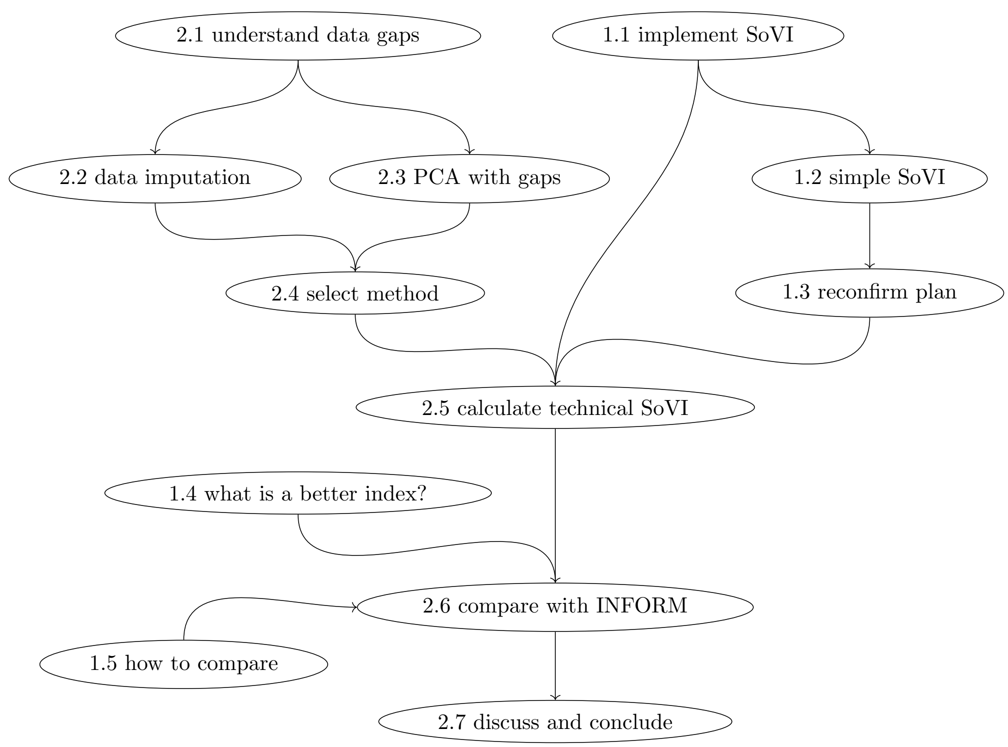


Figure 3: Task dependencies for the core project to compare the SoVI and INFORM indices (see Section 5).

The following tasks are suggested as a plan to investigate this research question. Of these, Tasks 1 and 2 together make up the core project; the remainder are extensions that could be investigated if time allows:

1. Simplistic SoVI:
    1.1. understand and implement the SoVI recipe
    1.2. calculate SoVI with some simplistic scenarios (for example using only the data rows with no missing values, using global or regional means or medians to substitute these values, etc)
    1.3. take note of the results, adjust and reconfirm the workplan as necessary

1.4. define *what* makes a ‘better’ index (eg. fewer countries left out, comparable results overall, explainable differences, reproducible method etc)

1.5. define *how* to compare the different indices, SoVI and INFORM (eg. looking for similarities and differences in the top 20)

2. Technical SoVI:

2.1. investigate *why* some countries are missing from the INFORM index; are some missing values more important than others?

2.2. investigate methods of data imputation that would be appropriate for this dataset

2.3. investigate methods for running PCA with missing values (eg. cellWise)

2.4. of the methods investigated above, choose the most effective to continue with

2.5. calculate SoVI using this technical solution to replace the missing values

2.6. compare technical SoVI with published INFORM using method defined above

2.7. discuss the results using domain knowledge and conclude which index meets our definition of ‘better’

3. Data-rich SoVI:

3.1. identify potential sources of additional data or proxies for missing data (possibly focusing specifically on one or two indicators)

3.2. attempt to get data and/or calculate proxies

3.3. if successful, calculate SoVI using the new data/proxies

3.4. compare data-rich SoVI with published INFORM using method defined above

3.5. discuss the results using domain knowledge and conclude which index meets our definition of ‘better’

4. INFORM:

4.1. if the INFORM implementation in R is available (see Section 7) **and** new data has been obtained, calculate data-rich INFORM

4.2. define *what* would make data-rich INFORM ‘better’ than published INFORM (eg. are additional countries represented, few and/or explainable differences in existing countries)

4.3. define *how* to compare published INFORM with data-rich INFORM (eg. counts of countries represented, what percentage difference might be acceptable in existing countries’ indices)

4.4. compare data-rich INFORM with published INFORM using method defined above

4.5. compare data-rich INFORM with data-rich SoVI using method defined above

4.6. discuss the results of both comparisons using domain knowledge and conclude which index meets our definition of ‘better’

5. Stretch target 1: indices

5.1. identify and implement a third index for measuring vulnerability to climate change

5.2. compare the results with SoVI and INFORM and discuss which is ‘better’

6. Stretch target 2: indicators
    6.1. looking at correlation and relative contribution to the calculation, identify some indicators to exclude and then recalculate SoVI
    6.2. if feasible, do the same with INFORM
    6.3. compare dropped-indicator SoVI with previously calculated indices as above
    6.4. discuss which of these indices best meets our definition of 'better'

6 Resources Estimation

Although the data used in this project is of global scope, it is highly summarised, so it is not envisaged that significant compute, storage or network resource will be needed. Further data to be obtained is also expected to be at a summary level, with the exception of geodata, which might be needed to act as a proxy for unavailable administrative data.

7 Risk Analysis

A list of potential risks to successful completion of the project is shown in Table 3.

8 Outline of the Dissertation Report

For the core project, the dissertation report is expected to have the following structure:

- Initial theory: Document how concepts such as Hazard, Risk, Exposure, Vulnerability, Mitigation, Adaptive Capacity are defined in the context of climate change. Consider how indices help us understand the relative risks, worldwide, and what the characteristics of a 'good' index might be. Understand how the INFORM and SoVI indices are calculated, and what their strengths and weaknesses are. Decide on a meaningful way to compare indices.
- Initial investigation: Implementing the SoVI index on the identical dataset used by UNICEF in creating their CCRI with the INFORM methodology, with a simplistic approach to missing values. Investigating methods of imputation that may be used to substitute for missing values. Investigating implementations of PCA that claim robustness to missing values.
- Review/consolidate: Considering the results of these investigations and justifying a choice of methodology to use in this project.
- Implementation: Recalculate SoVI using the chosen solution to replace missing values. Compare the resulting index with that created with the INFORM methodology, using the method decided on above.
- Conclusions: Discuss the results of this comparison bringing in domain knowledge, and conclude which index has more of the characteristics of a 'good' index, as defined above.

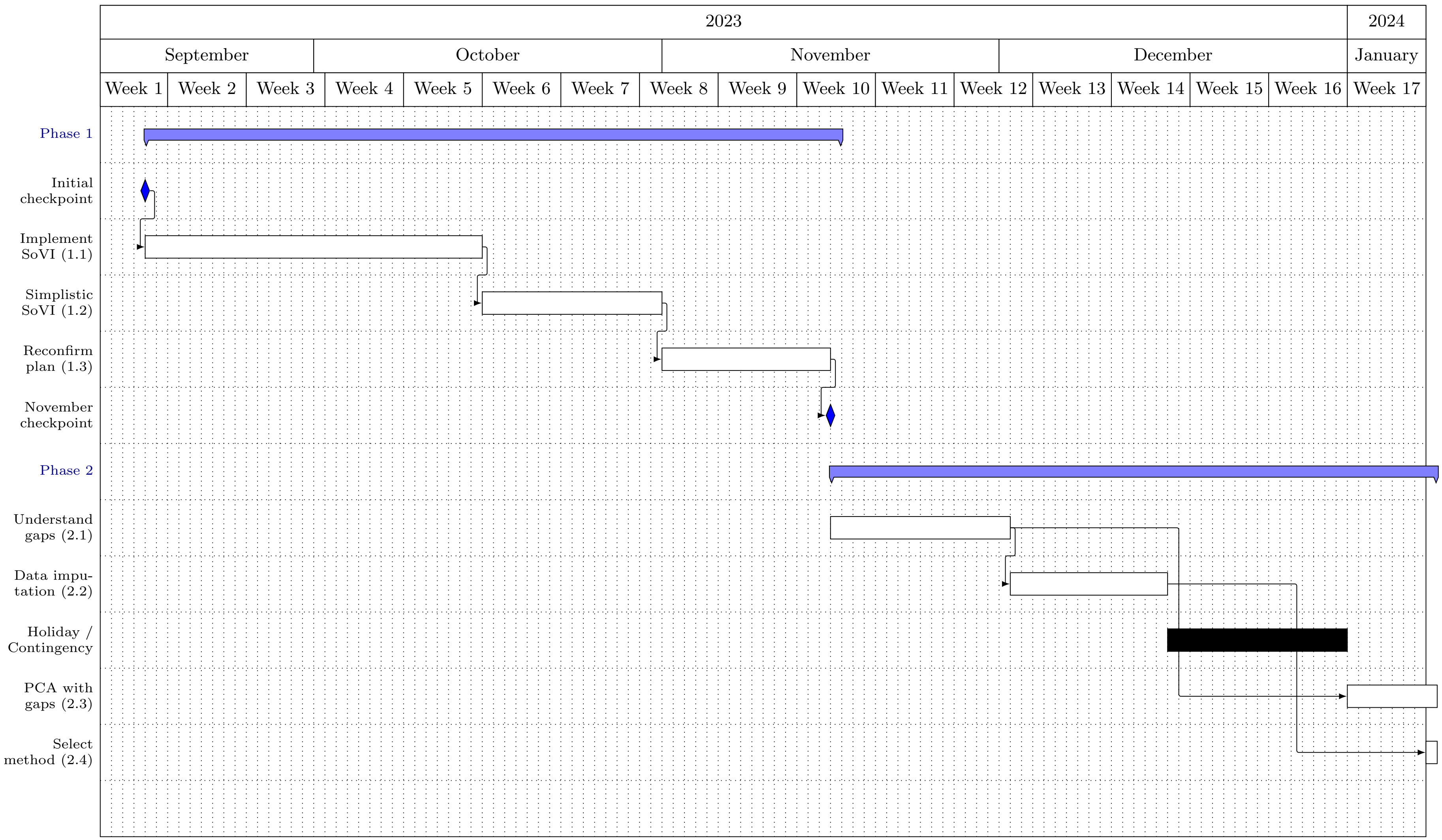
If it is possible to implement some of the additional tasks, their methods and results will be integrated into this plan, rather than being added as standalone chapters.

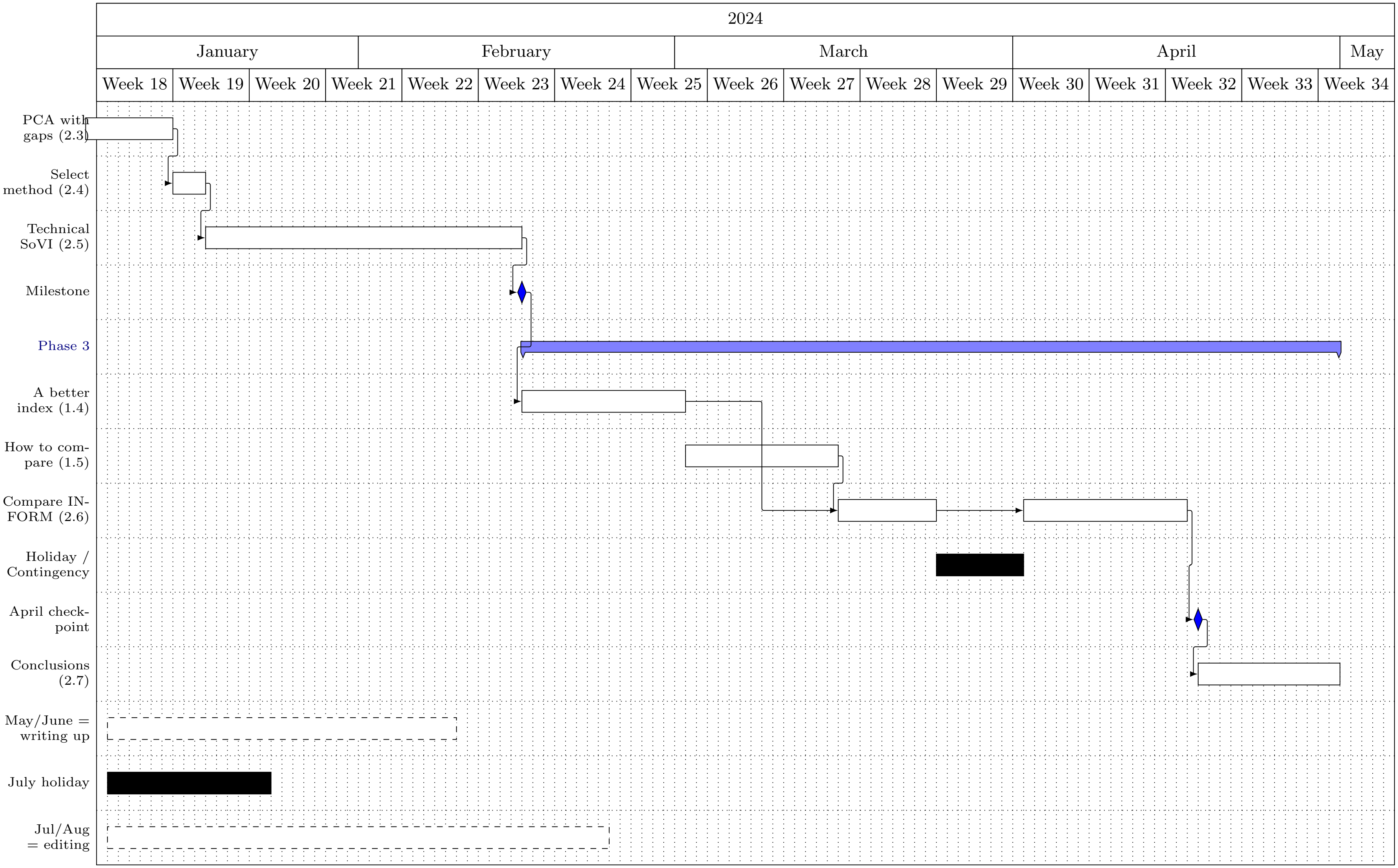
Risk	Probability	Impact	Management
a brief description of a risk to project completion	*unlikely, possible, probable or certain*	*negligible, moderate, severe and catastrophic*	*how to avoid or mitigate the risk*
A. Time spent looking for new data sources does not yield sufficient results	probable	Limits the analyses that are possible: the core project could be completed with no new data, as could stretch:indicators and stretch:indices; stretch:data and stretch:INFORM could not	The plan has been structured so that the core project does not depend on new data, and neither do some of the stretch goals; Set a time limit for investigating potential data sources in advance: data investigations could be run alongside other work at no more than half a day/week until the end of the first term (Dec. 2023)
B. Student's project to implement INFORM in R not available	possible	Will prevent variations on the SoVI/INFORM comparison being carried out, specifically stretch:INFORM and stretch:indicators	The core project, stretch:indices and stretch:data could provide sufficient work; At initial checkpoint (Sept. 2023) can confirm whether or not this will be part of the project plan
C. Insufficient domain knowledge to explain results	possible	severe, see mark scheme for detailed impact	Plan sufficient time for an extensive literature review; Add checkpoints to revisit the lit review during the project, to ensure any new concepts are covered
D. Composite risk: both A and B	possible	In this scenario only the core project and stretch:indices could be carried out	Use the checkpoints (Sept. 2023, January 2024) and additional knowledge gained to explore additional stretch targets that might be included, if content is insufficient

Table 3: Potential risks to the success of the project, their likelihood of occurrence, impact on the project and approaches for their management (see Section 7).

A Timeline for the core project

The following two pages show the tasks of the core project as a Gantt chart. It is expected that this plan will be reviewed and updated at the project checkpoints, and possibly more frequently.


2023
2024
September
October
November
December
January
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12
Week 13
Week 14
Week 15
Week 16
Week 17
Phase 1
Initial checkpoint
Implement SoVI (1.1)
Simplistic SoVI (1.2)
Reconfirm plan (1.3)
November checkpoint
Phase 2
Understand gaps (2.1)
Data imputation (2.2)
Holiday / Contingency
PCA with gaps (2.3)
Select method (2.4)


2024
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Week 29
Week 30
Week 31
Week 32
Week 33
Week 34
PCA with gaps (2.3)
Select method (2.4)
Technical SoVI (2.5)
Milestone
Phase 3
A better index (1.4)
How to compare (1.5)
Compare INFORM (2.6)
Holiday / Contingency
April checkpoint
Conclusions (2.7)
May/June = writing up
July holiday
Jul/Aug = editing

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