# Assessing Heat-Health Vulnerabilities in Urban Africa: An Interdisciplinary Study of Climatic Impacts and Public Health Resilience

## PhD proposal of Mr Craig Parker 02/08/2023

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## Summary

This research proposal focuses on a comprehensive examination of heat-health interactions in large African cities, with a particular emphasis on Johannesburg. Our revised objectives include a multi-dimensional analysis of urban heat vulnerability, the use of machine learning explanatory models to understand complex health outcomes, and the development of predictive models for heat-health impacts. These objectives align with our broader goal of providing actionable insights for public health interventions in the context of climate change.

**Objective 1: Mapping Urban Heat Vulnerability** The first objective involves an integrated analysis combining socio-economic survey data with spatial information, derived from sources like Copernicus ERA5 reanalysis and Landsat imagery. We aim to map intra-urban heat vulnerability and exposure by employing Principal Component Analysis (PCA) for identifying key predictors. This will be followed by multi-level clustering to categorize urban areas into different vulnerability profiles based on socio-economic and environmental data.

**Objective 2: Explanatory Modeling of Heat-Health Relationships** Our second objective shifts the focus to explanatory modeling using advanced machine learning techniques. We will utilize methods like Random Forests and XGBoost to understand the intricate, non-linear, and time-lagged relationships between environmental factors and health outcomes. This phase is crucial for elucidating the underlying mechanisms of heat-health interactions in the urban setting of Johannesburg.

**Objective 3: Predictive Heat-Health Outcome Modeling** The final objective is centered around constructing a predictive model for heat-related health outcomes. This model will be informed by the insights gathered from the initial stages of our research and will focus on identifying socio-economic and environmental conditions that heighten health risks. We will employ a range of supervised machine learning techniques, ensuring the model’s predictive accuracy, and apply metrics like AUC-ROC for evaluation. The predictive model aims to stratify risk across different demographic groups, thereby aiding in targeted health interventions and resource planning.

**Conclusion** By intertwining these methodologies, our research aims to provide a comprehensive and nuanced understanding of how heat impacts health in urban environments like Johannesburg. The outcomes of this study are expected to offer valuable guidance for public health strategies and interventions in similar urban settings facing the challenges of climate change.

## Introduction:

Climate change has led to a significant increase in global temperatures, particularly in rapidly urbanizing African cities, exacerbating the public health risks associated with high ambient temperatures and heat waves 1,2. The Urban Heat Island (UHI) effect, caused by urban development and lack of vegetation, further intensifies these vulnerabilities, leading to considerably higher temperatures within cities compared to their surrounding rural areas 3. This phenomenon is particularly concerning as structures within these cities, such as informal dwellings and low-cost housing, are often inadequately designed for such conditions, resulting in indoor temperatures that are 3-4°C warmer than outside, thereby exacerbating heat exposure 4,5.

The unique vulnerabilities in African urban settings, including high prevalence rates of diseases like HIV and TB, limited access to cooling resources, and large populations residing in informal settlements, further compound the health risks associated with rising temperatures 6,7. Despite the widely recognized health impacts of heat, there is a critical knowledge gap in assessing and predicting heat-related health risks within the African city context 8,9. Existing heat-health impact assessments often fail to account for the complexity of urban spaces, unique environmental exposures, and specific demographic and disease spectrums in Africa 10.

Preliminary research in Johannesburg has indicated that indoor classroom temperatures often exceed comfortable levels, leading to symptoms such as fatigue and difficulty breathing among students, while waiting rooms in rural clinics have recorded temperatures exceeding 38°C, potentially causing considerable discomfort and health impacts for patients seeking treatment. In response to these challenges and knowledge gaps, a proposed PhD project aims to rigorously examine the socio-economic and environmental vulnerabilities within Johannesburg's urban landscape. The project will utilize advanced machine learning explanatory models to scrutinize and interpret the intricate dynamics of heat-health interactions, particularly focusing on the time-lagged effects of heat exposures. Additionally, the project aims to develop a sophisticated predictive model that incorporates spatial and demographic nuances to accurately forecast adverse health outcomes linked to varying temperature thresholds, with the goal of guiding the development of targeted interventions and long-term urban planning strategies to mitigate heat exposure and enhance resilience against climate change 4,5.

In conclusion, the proposed research seeks to significantly deepen the understanding of heat-related health risks in urban settings across African cities and contribute to the field of urban public health, particularly in the context of the changing climate. By advancing knowledge and capabilities in predicting and responding to heat-health challenges, the research aims to lay the groundwork for fostering more resilient urban environments in Africa.

## Study Setting

Nestled on the Highveld plateau at an elevation of 1,753 meters, the vibrant city of Johannesburg forms the centerpiece of our research. As the largest city in South Africa and the 26th largest globally, Johannesburg's population exceeds 5.635 million inhabitants[16]. This bustling metropolis, characterized by its unique subtropical highland climate, provides a compelling backdrop for exploring urban heat health impacts[17].

Johannesburg's distinct weather patterns follow a bifurcated climate cycle. Summer months, extending from October to April, are marked by hot days often followed by refreshing afternoon thundershowers, subsequently transitioning into cooler evenings. The winter period from May to September offers a contrasting spectacle of dry, sunny days leading into cold nights. Due to the city's high elevation, the climate remains generally mild, with average maximum daytime temperatures oscillating between 25.6 °C (78.1°F) in January and 16 °C (61°F) in June.

Johannesburg's socio-economic canvas is marked by stark disparities, with impoverished urban communities shouldering the disproportionate burden of climate change impacts on health and well-being[18]. Inadequate housing, limited access to resources, and poverty elevate these communities' vulnerability to heat-related health effects, a situation worsened by infrastructural deficiencies[17].

From a health standpoint, a unique set of risk factors shapes the relationship between heat and health in Johannesburg. Adverse health outcomes linked to heat exposure include high blood pressure, respiratory stress, and cardiac conditions, all further aggravated by the prevailing socio-economic and infrastructural conditions[1, 19, 20]. A critical health consideration in Johannesburg is the prevalence of communicable diseases, notably HIV, Tuberculosis, and COVID-19 [21, 22]. These diseases add complexity to the health landscape, with heat exposure potentially affecting the health status and disease progression in affected individuals.

Heatwaves pose a significant public health risk in Johannesburg[17]. Research has revealed temperature thresholds associated with a heightened risk of mortality. Such insights emphasize the importance of characterizing past and future heatwaves to enhance heat health warning systems and inform health-centric policy-making[23].

Against the backdrop of the Urban Heat Island (UHI) phenomenon, the myriad socio-economic inequalities, infrastructural challenges, and health-related considerations in Johannesburg make it an ideal study site for our research[24]. By dissecting these complexities in the context of climate, we aim to enhance our understanding of the multi-layered relationships between urban heat exposure, population vulnerability, and health outcomes. These insights will serve as valuable inputs for the evolution of heat health warning systems and policies designed to safeguard the most vulnerable from the health impacts of heat exposure.

## Aims and Objectives:

The primary objective of this research study is to deepen our understanding of the complex, spatially, and demographically stratified heat-health interactions common in large African cities.

1. **Map intra-urban heat vulnerability and exposure across urban areas in large African cities, quantifying the intra-urban socio-economic and environmental vulnerability (Aim 1).**
2. **Employ machine learning explanatory models to uncover and interpret the intricate relationships between climate variables and health outcomes in Johannesburg, enhancing our understanding of heat-health dynamics with a focus on explainability and interpretability of model findings (Aim 2).**
3. **Develop a spatially and demographically stratified heat-health outcome prediction model that can predict the probability of adverse health outcomes at different temperature thresholds (Aim 3)**

Figure 1: Summary of study aims.



## Data Description

This research will utilize a vast array of data sources to achieve its objectives. All data will be housed and managed within the high-performance computing facilities at the University of Cape Town's Climate System Analysis Group (UCT CSAG), a central asset developed as part of the HE2AT center project. Details of the data management plan that oversees this system can be provided upon request.

**Socio-economic and Health Data:** We will incorporate socio-economic survey data to provide insights into the economic status, living conditions, and demographic and environmental characteristics of households. Key datasets will include:

* The Gauteng City Region Observatory (GCRO) Quality-of-Life survey (2020/21)
* South African national censuses, including Census 2011
* Community Survey 2016

Health-related data will be sourced from longitudinal datasets involving both HIV-infected and uninfected adults, as well as adults in studies related to COVID-19 prevention or treatment within Johannesburg. This will cover a spectrum of data from social, economic, and demographic variables to geospatial locations, health statuses, and medical findings. This broad inclusion criteria ensures comprehensive coverage of the adult population involved in these primary studies.

**Spatial and Environmental Data:** Spatial proxies for socio-economic conditions will be derived from various sources, including:

* Satellite imagery for land use and cover estimations
* Data on access to services such as electricity and healthcare
* Proximity to green spaces
* Google Street View analyses
* SEDAC's gridded human population data

**Climate and Weather Data:** We will leverage climate and weather data from a combination of historical records and model-based reanalysis. These datasets will integrate observations from a global network of sources, including weather stations and satellites, with numerical weather simulations. Specific datasets will include:

* MODIS and LANDSAT for Land Surface Temperature (LST)
* The UK Met Office/IMPALA CP4-A for high-resolution climate simulations over Africa
* TAHMO weather stations
* World Meteorological Organization (WMO) Global Summary Of the Day (GSOD) weather data
* ECMWF ERA-5 re-analysis for regional atmospheric conditions
* ECMWF ERA5-Land for land-based data assimilation

**Model Development Data:** For developing the heat-health outcome prediction model, we will revisit the health data, now in conjunction with the collected climate and environmental data. Collaboration with Principal Investigators and data repositories will enrich our dataset, allowing for a detailed cross-referencing of weather and health data.

This comprehensive approach to data collection and management is designed to enable a multifaceted analysis of the relationship between heat exposure and health outcomes in Johannesburg, ensuring a robust empirical foundation for the research.

## Methods

### Quantifying Intra-Urban Socio-Economic and Environmental Vulnerability

Our approach to quantifying intra-urban socio-economic and environmental vulnerability is rooted in a sophisticated statistical framework designed to distil the multifaceted nature of urban vulnerability into an actionable synthesis.

We commence with dimensionality reduction, sifting through the complex tapestry of socio-economic and environmental factors to isolate those with the most significant impact on urban socio-economic variability. By deploying a Principal Component Analysis (PCA)-based automated variable selection, we pinpoint pivotal inputs for geodemographic classifications from diverse variables. This technique, informed by precedents like the UK 2011 Census analysis, enhances the quality of cluster assignments, evidenced by optimised within-cluster sum of squares.

Utilising PCA, we foreground the dataset's inherent variation and bring into relief the most telling patterns, thus streamlining the dataset's complexity. This process not only elucidates but prioritises key predictors, allowing us to capture the essence of variability within the urban milieu.

Subsequently, we craft a composite indicator by weaving together these principal components. This composite metric embodies the aggregate socio-economic and environmental vulnerability, focusing on heat vulnerability as the primary climatic risk under scrutiny.

The culmination of our analysis is producing a detailed vulnerability map via a spatial multi-criteria analysis. This cartographic output becomes an invaluable instrument in spotlighting areas of heightened vulnerability, thereby informing targeted interventions and optimising resource distribution for enhanced urban resilience.

A diagram of a company

Description automatically generated

Figure 2

## **Delineating Time-Lagged, Non-Linear Heat-Health Dynamics through Explanatory Machine Learning Models**

Our approach leverages the strengths of explanatory machine learning models like Random Forests and XGBoost to dissect and understand the time-lagged, non-linear interactions between socio-economic, and environmental vulnerabilities, and health outcomes in Johannesburg. This phase focuses on explanation rather than prediction, aiming to illuminate the underlying mechanisms that drive these complex relationships.

Random Forests will be used for their interpretability and ability to rank features based on their importance. This model's intrinsic randomisation, coupled with an ensemble approach, provides a robust framework for capturing the most significant predictors without explicit variable exclusion. The model's output on feature importance will guide our understanding of the key determinants and their respective influence on health outcomes.

XGBoost, known for its precision in handling diverse data types and structures, will be employed to detail the nuances of the data. Its feature selection and regularisation capability makes it an optimal choice for identifying and interpreting critical features. We will exploit XGBoost's SHAP values to interpret the contribution of each feature within the context of time-lagged effects, thus emphasizing the explanatory aspect of our analysis.

In adherence to best practices and the feedback provided, we will utilise the entire dataset for our explanatory models to allow the machine learning algorithms to internally assess the importance of each feature without withholding any portion of the data for hold-out validation. This approach ensures that our interpretation of the model is based on the complete information available, providing a comprehensive view of the heat health dynamics at play.

Our commitment to methodological rigor involves performing a sensitivity analysis to validate the consistency and reliability of the feature importance outcomes. By examining how variations in the data affect the model results, we can confirm the stability of our explanatory factors.

The interpretative power of machine learning will be harnessed to its fullest to uncover the temporal and complex associations within our urban health data, offering clear insights into the interactions between the environment, time, and health. This will enable stakeholders to grasp the multifaceted nature of heat-health vulnerabilities and craft targeted interventions informed by a thorough understanding of the determinants.

Through this focused and methodologically robust approach, we aim to provide a transparent and detailed explanation of the factors that contribute to heat-related health risks, contributing significantly to the field of urban public health research.

Figure 3:

### Developing a Spatially and Demographically Stratified Heat-Health Outcome Forecast Model

As we refine our strategy for predicting heat-health outcomes, we turn to the sophisticated methodology of transfer learning, which allows us to leverage pre-trained models and apply their learned patterns to our specific context.

**Initial Model Development and Transfer Learning Integration:** We will begin by evaluating various machine learning architectures, including deep neural networks, which have shown great promise in capturing complex, high-level abstractions in data. Pre-trained models from similar domains, such as meteorological prediction or health diagnostics, will be fine-tuned with our heat-health datasets. This approach enables the model to start with an advanced understanding of patterns and relations, potentially accelerating the learning process and improving predictive performance.

**Model Fine-Tuning with Domain-Specific Data:** Our data will be used to fine-tune these models, allowing them to adapt to the specific nuances of heat-health interactions within Johannesburg. We will employ techniques such as feature extraction, where layers from pre-trained networks are repurposed as feature generators for our predictive model, enhancing its ability to discern relevant patterns that directly impact health outcomes.

**Ensemble and Hybrid Approaches:** To bolster predictive power, we will explore ensemble methods that combine the strengths of both traditional machine learning algorithms like XGBoost and deep learning models. This hybrid approach aims to blend the interpretability and statistical strengths of algorithms like XGBoost with the high-dimensional pattern recognition capabilities of deep learning architectures.

**MLOps Pipeline and Transfer Learning:** Our MLOps pipeline will be specifically designed to accommodate the continuous evolution of these models. Key components will include:

1. **Automated Retraining Loops:** To regularly update the model with new data, ensuring that the transfer learning process is ongoing and the model remains attuned to the latest trends.
2. **Model Validation Frameworks:** Rigorous validation frameworks that test the transfer-learned models against both internal and external datasets, ensuring that the models generalize well beyond the training data.
3. **Model Serving and Monitoring:** Deployment of the model into a production environment with robust monitoring to observe model performance and detect any deviations or shifts in input data distributions.
4. **Feature Store Updates:** Synchronization of the feature store with the latest feature engineering techniques adapted from the pre-trained models, ensuring that all models in production have access to the most predictive features.

**External Dataset Validation and Model Generalization:** With an eye on future deployment in diverse urban centers, we will set the stage for validating our models against external datasets from different geographies. This step will be critical to assess the generalizability of our transfer-learned models and to fine-tune them for broader applications.

**Deployment and Real-World Application:** involving real-time data processing and predictive model serving, are beyond the scope of this PhD research. The current study aims to lay the groundwork for such advancements by developing robust predictive models. Actual deployment, with infrastructure for real-time health risk assessments, is envisioned as a potential future extension post-PhD.

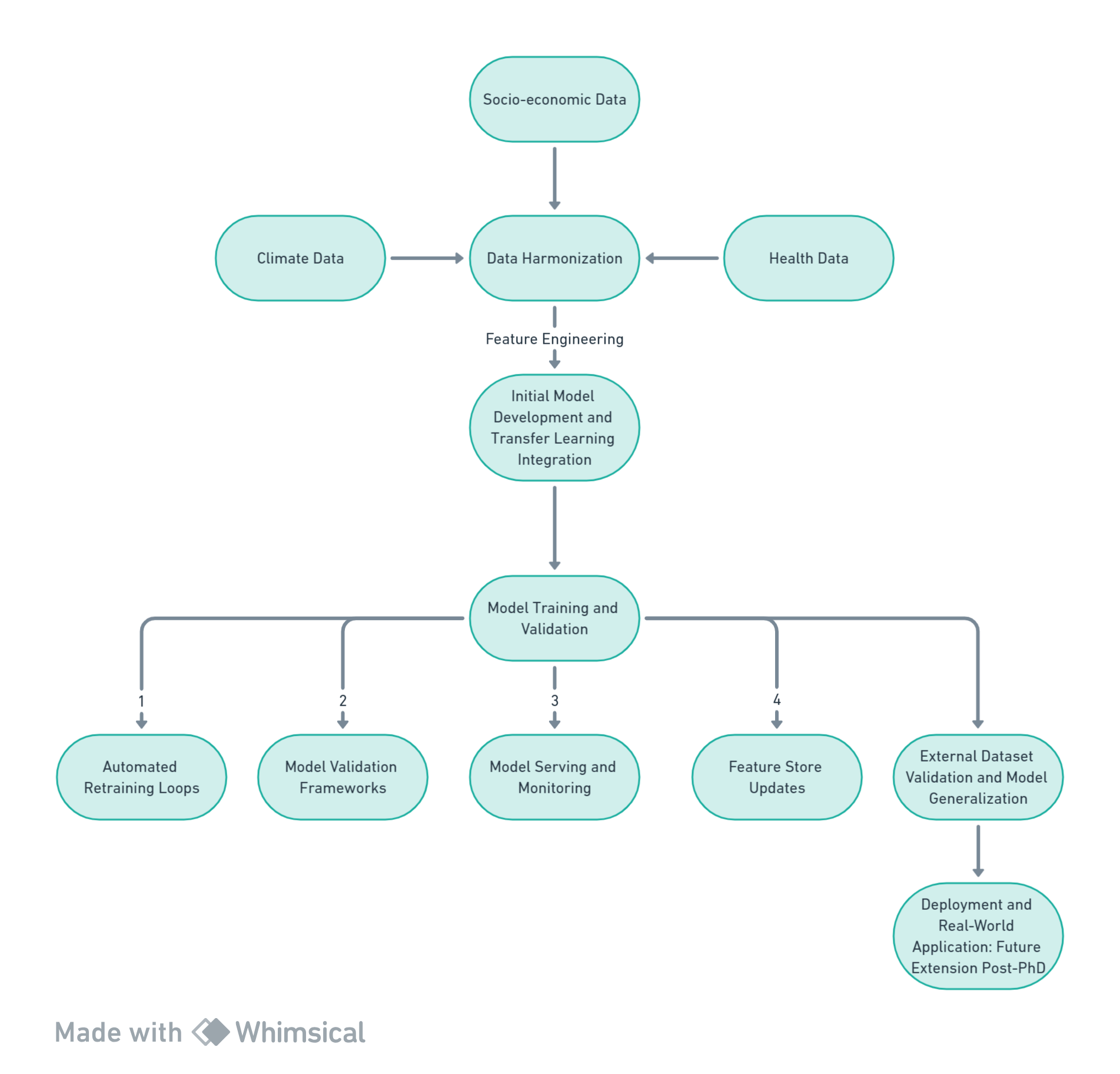


Figure 4: Stratified Heat-Health Outcome Forecast Model Development Process

## Potential Post-PhD Study: Explanatory Modeling with Synthetic Data

A potential extension of this research could explore the efficacy of synthetic data in replicating the explanatory modeling performed in Aim 2. The focus would be to generate synthetic datasets that closely mimic the statistical properties of the original data, then apply the same machine learning techniques to extract insights.

This study would specifically evaluate whether the relationships and importance of features identified through the original data are preserved when using synthetic data. Success in this endeavor would indicate that synthetic data can replace actual patient data in situations where privacy concerns or data-sharing restrictions exist. This could pave the way for a privacy-preserving methodology in collaborative heat-health research, particularly beneficial for cross-border data sharing within the heat-health research community

|  |  |  |
| --- | --- | --- |
| Aim | Description | Key Methods |
| 1 | Quantifying Intra-Urban Socio-Economic and Environmental Vulnerability | Principal Component Analysis (PCA) to identify key predictors, Spatial Principal Component Analysis for spatial variability, Multi-level clustering to group regions with similar vulnerability profiles, Spatial multi-criteria analytic method to generate the final output map |
| 2 | Utilizing Statistical and Machine Learning Methodologies to Understand Heat-Health Exposures and Their Impacts in Johannesburg | Distributed Lag Non-linear Model (DLNM) to assess lag–response relationships, Machine learning techniques (decision trees, random forests, gradient boosting, deep learning models) for pattern recognition, Time-series and survival analysis for temporal dynamics, Cross-correlation analysis for lagged effects |
| 3 | Developing a Spatially and Demographically Stratified Heat-Health Outcome Forecast Model | Supervised machine learning techniques (regression, decision trees, random forests, K-means clustering, support vector machines) for predictive modeling, Stratification methods for sub-group discovery, Selection of optimal algorithms based on engagement with health practitioners and researchers, Use of Aim 1 and Aim 2 outputs as inputs for model prediction |

Table 1: This table provides an overview of the specific techniques and processes to be used in each aim.

## Ethical Considerations:

Ethics and Privacy Considerations for the Study on Heat-Health Exposures in Johannesburg

This doctoral research, examining the impacts of heat-health exposures in Johannesburg, is committed to respecting and protecting the rights of the individuals represented in our secondary health datasets. The study design acknowledges and addresses several ethical considerations and legal requirements, including the use of secondary data for new research purposes, the handling of potentially identifying information, and the necessity for robust data management.

We have obtained ethical clearance from the University's ethical committee (HE2AT Center HEAT002: 220606 Wits Human Research Ethics Committee) and will continue to strictly adhere to the University's ethical approval procedures throughout the course of this research. Our commitment to ethical excellence ensures that any data collected from human participants is gathered, analyzed, stored, and shared securely and ethically.

Guided by globally recognized guidelines, including the Declaration of Helsinki, ICH Good Clinical Practice, and the Ethics in Health Research (Department of Health South Africa), as well as the Protection of Personal Information Act (POPIA), our research aims to safeguard the interests of the individuals while serving the public interest.

The objectives of the research are transparently defined, and the reasons for involving personal data are clearly elucidated. To honour the principles of informed consent, we are respecting the conditions of data use as per the original data collection. We are prepared to seek re-consenting or apply for an informed consent waiver from the ethics committee for 'narrow' or 'tiered consent' datasets, if necessary.

In compliance with the provisions set forth by POPIA and other data security laws, a detailed data management plan will be implemented. This plan will cover secure data transfer, storage, and access, with strict controls limiting access to necessary personnel only. Data will be anonymized when required, and our commitment extends to ensuring that publications from this research will not contain any potentially identifiable information from participants.

In conclusion, we believe these measures not only meet ethical and legal requirements but also respect and protect the rights of the individuals represented in our datasets. Our commitment to maintaining high ethical standards throughout this research underscores our dedication to both scientific rigor and the welfare of the public.

## Work Plan:

|  |  |  |
| --- | --- | --- |
| Year | Activities | Outcomes |
| 1 | Conduct a comprehensive literature review. Establish research protocol. Draft first paper on intra-urban heat vulnerability. | First paper draft on intra-urban heat vulnerability. |
| 2 | Analyze GCRO and climate data. Inform second paper on intra-urban socio-economic and environmental vulnerability. | Second paper on socio-economic and environmental vulnerability. |
| 3 | Apply advanced statistical and machine learning techniques. Investigate lagged impacts of heat-health exposures. Draft third paper on heat and health associations. | Third paper on lagged impacts of heat-health exposures. |
| 4 | Develop and refine a predictive model. Evaluate model performance. Document model development in fourth paper. Complete PhD thesis. | Fourth paper on predictive model. Completed PhD thesis |

## Research Outputs

Our research endeavors will culminate in the publication of four seminal papers, each highlighting a key facet of our investigation into heat-health outcomes in Johannesburg. These papers are pivotal to our academic contribution and will be disseminated widely for maximal impact.

1. **Research Protocol Documentation Paper**: This initial paper will outline the comprehensive research protocol used in our study. It will detail the methodological framework, aiming to provide a replicable model for similar studies. This paper's public availability will not only validate our scientific approach but also encourage further research in this vital domain.
2. **Socio-economic and Climate Vulnerability Analysis Paper**: The second paper will delve into the socio-economic and climate data analysis, focusing on identifying the vulnerability traits within the Johannesburg population. We plan to present these insights at scientific conferences and publish in open-access journals, stimulating discussions that extend beyond the academic sphere and contribute to a broader understanding of the socio-economic impacts of climate change.
3. **Heat-Health Correlations and Explanatory ML Modeling Analysis Paper**: The third paper will showcase the results of using advanced statistical and machine learning explanatory models to analyze the complex relationships between temperature fluctuations and health outcomes, particularly focusing on the time-lagged impacts of heat exposure in Johannesburg. This paper will highlight the efficacy of explanatory ML models in unraveling these intricate relationships, providing valuable insights that can inform future research directions and public health policy decisions.
4. **Heat-Health Outcome Prediction Model Paper**: The final paper will focus on the development and validation of our heat-health outcome prediction model. It will detail the model's efficacy in forecasting health risks and its potential to guide risk mitigation strategies. By sharing this model, we seek to foster proactive, data-driven public health initiatives, both locally in Johannesburg and in similar urban contexts globally.

These papers will form the cornerstone of our scientific communication and outreach, underpinning presentations at academic forums and engagements with community and policy stakeholders. They are intended to significantly contribute to the scholarly dialogue on climate and health, while also informing public policy, raising awareness, and guiding future adaptation strategies in the face of climate change



## POPIA compliance and protection of personal information

In alignment with the Protection of Personal Information Act of South Africa (POPIA, 2013), our research meticulously attends to data security and confidentiality. POPIA sets limitations on personal information processing but simultaneously allows for its use in scientific research. Our study is cognizant of this, alongside other governing legal frameworks like the National Health Act No 61 of 2003, the Constitution of the Republic of South Africa, and Department of Health guidelines on Ethics in Health Research.

Our research strategy includes processing de-identified health databases in which re-identification is virtually impossible. Where personal information has not been de-identified, we comply with the relevant sections of POPIA, allowing us to process health data for historical, statistical, and research purposes.

The information gathered and processed by our team will only be used for research and statistical purposes, which directly relate to addressing the major public interest of understanding and mitigating the health implications of rapidly escalating temperatures and heat waves, particularly in Africa. This processing of data is deemed necessary and justified as it serves to inform strategies to combat one of the greatest health threats of the 21st century – climate change.

Security measures will be implemented to prevent unlawful access or processing of personal information, while the operators involved in the data handling process will be bound by a written contract, ensuring accountability. This approach aligns with Sections 19, 20, and 21 of POPIA, demonstrating our commitment to preserving the rights of individuals and upholding the highest ethical standards in scientific research.

## Strengths and Weaknesses

**Strengths**

1. **Integrated Explanatory and Predictive Approach**: The proposal synergizes explanatory machine learning models and predictive analytics, blending socio-economic data, satellite imagery, and advanced statistical techniques. This comprehensive approach enhances the depth and scope of the research, offering both understanding and forecasting capabilities for heat-health dynamics.
2. **Targeted Vulnerability Mapping**: The research emphasizes identifying and categorizing urban regions based on vulnerability profiles. This focus is particularly pertinent in the context of climate change and urban health, addressing a critical need for targeted intervention strategies.
3. **Utilization of Diverse Data Sources**: By leveraging existing health datasets, climate and weather data, and socio-economic information, the research is grounded in a rich empirical base. This reliance on varied data sources ensures that the insights generated are robust and relevant to real-world scenarios.
4. **Innovative Machine Learning Deployment**: The application of machine learning, especially the use of explanatory models, adds a novel dimension to the study. It allows for a deeper understanding of complex, non-linear relationships between variables, which is crucial for developing effective public health responses.

**Weaknesses**

1. **Data Dependency and Quality Concerns**: The study's success is heavily reliant on the availability and quality of diverse datasets. Challenges related to data integrity, accessibility, and integration could impact the research outcomes.
2. **Methodological Complexity**: The multifaceted nature of the approach, combining different data types and advanced analytical techniques, may introduce complexity that requires meticulous management and methodological precision.
3. **Contextual Limitations in Generalizability**: Focusing primarily on Johannesburg, the study's findings might have limited direct applicability to other African cities or diverse urban environments. Although the specific focus allows for an in-depth local analysis, expanding the framework for broader applicability could enhance the proposal's impact.
4. **Challenges in Model Interpretability**: While machine learning models, particularly explanatory ones, offer deep insights, there can be challenges related to interpretability and the explanation of complex model outputs, which are critical for informing policy and public health decisions.

## Budget

1. **Software Licenses**: The budget encompasses the licensing costs for specialized software used in data analysis and model building, including statistical software, machine learning libraries, GIS software, and data visualization tools.
2. **Cloud-Based Computing Resources**: Recognizing the need for high-performance computing, particularly for predictive modeling, we will allocate a significant portion of the budget to Google Cloud Computing services. This will support the computational demands of machine learning algorithms and large-scale data processing, ensuring efficiency and scalability.
3. **Hardware**: The project will also invest in acquiring suitable hardware or subscribing to additional cloud-based computational services to support data analysis.
4. **Publication Fees**: We anticipate expenses related to publishing our findings in open-access, peer-reviewed journals to ensure wide dissemination of our research.
5. **Training and Capacity Building**: The budget provides for ongoing training to keep the research team updated with the latest developments in data science and climate-health research.

The budget aligns with the funding limits of the National Institutes of Health (NIH) grant. Considering the project's scale and scope, we may explore additional funding sources, including grants, research partnerships, or institutional collaborations, to fully realize our research objectives.

## Advisors

This research will be supported by an outstanding team of advisors, each bringing their vast knowledge and expertise in the intertwined disciplines of health and climate science.

Professor Matthew Chersich, based at Wits RHI, offers a wealth of experience in public health research that is invaluable to our study, particularly the health-related aspects. His career, spanning over two decades, has been focused on medical and public health research in Africa, particularly on maternal health and HIV, and recently on climate change and health. He has an extensive academic background in clinical medicine and public health, contributing to 14 WHO guidelines or monologues and serving as a contributing author to the Africa chapter of the 6th Intergovernmental Panel on Climate Change report. He has published more than 175 papers in peer-reviewed journals and has a significant H-Index of 48.

Professor Akbar Waljee of the University of Michigan brings crucial experience in statistical modelling and machine learning, essential for our data analysis and predictive modelling. Born in Kenya and educated in the United States, Prof. Waljee leads several key data and healthcare initiatives at the University of Michigan and the VA Ann Arbor Healthcare System. His work primarily involves utilizing machine learning and deep learning techniques to enhance healthcare access, quality, and efficiency, particularly in resource-constrained settings. His innovative work in decision support systems and personalized care is set to revolutionize patient care in gastroenterology and liver disorders in under-resourced settings globally.

Dr. Christopher Jack from the University of Cape Town strengthens the climate aspects of our study with his extensive knowledge in climate science, ensuring a well-rounded and sophisticated understanding of the climate-health nexus. With a background in computer science and ocean/atmospheric science, Dr. Jack possesses a unique blend of skills in high performance computing, modeling, analysis, science-society engagement, and decision-making under uncertainty. His current research activities are concentrated on the intersection of urban contexts and climate risk, leveraging his comprehensive expertise in climate science and modeling, and his proficiency in decision support and capacity development. His passion lies in working with and across diverse disciplines in complex problem spaces, making him especially interested in urban climate resilience in developing contexts.

Together, these advisors contribute a multidisciplinary perspective to our research, enriching its depth and breadth, and enhancing its potential impact.

## Conclusion

This research project seeks to explore the intricate relationship between urban heat exposure, population vulnerability, and health outcomes within the unique socio-economic, environmental, and climatic context of Johannesburg. Utilising advanced statistical techniques, machine learning methods, and a variety of robust data sources, the research aims to establish a nuanced understanding of heat-health effects in the city. This will culminate in the development of a spatially and demographically stratified heat-health outcome prediction model, which will enhance the city's readiness and response to heat-related health risks, ultimately contributing to the wellbeing of Johannesburg's inhabitants. As global temperatures continue to rise, the insights generated from this study could provide pivotal contributions to climate science, public health, AI, and the broader interdisciplinary field of climate and health.

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