Explainable AI for Heat-Health-Socioeconomic Interactions in Johannesburg

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61%
Glucose Variance
Predictable from Climate

1,300x
Vulnerability Range
Unprecedented Stratification

21-DAY
Optimal Exposure
Paradigm Shift Discovery

2,334
Participants from
Johannesburg Clinical Trial Dataset

Background & Research Gap

The Challenge:
- African cities experiencing unprecedented heat exposure
- Limited understanding of heat-health relationships in African contexts
- Traditional methods cannot capture complex interactions

Our Innovation:
- First comprehensive XAI analysis for African urban heat-health
- Integration of climate, biomarkers, and socioeconomic data
- SHAP reveals mechanistic pathways beyond correlations
- Actionable insights for climate adaptation in resource-limited settings

Methodological Approach

1. Data Integration
Climate: ERA5, WRF, MODIS
Health: 19 biomarkers
Socioeconomic: GCRO

2. Feature Engineering
Temporal lags (1-90 days)
Interaction terms
SE vulnerability indices

3. ML Modeling
Random Forest
XGBoost
Gradient Boosting

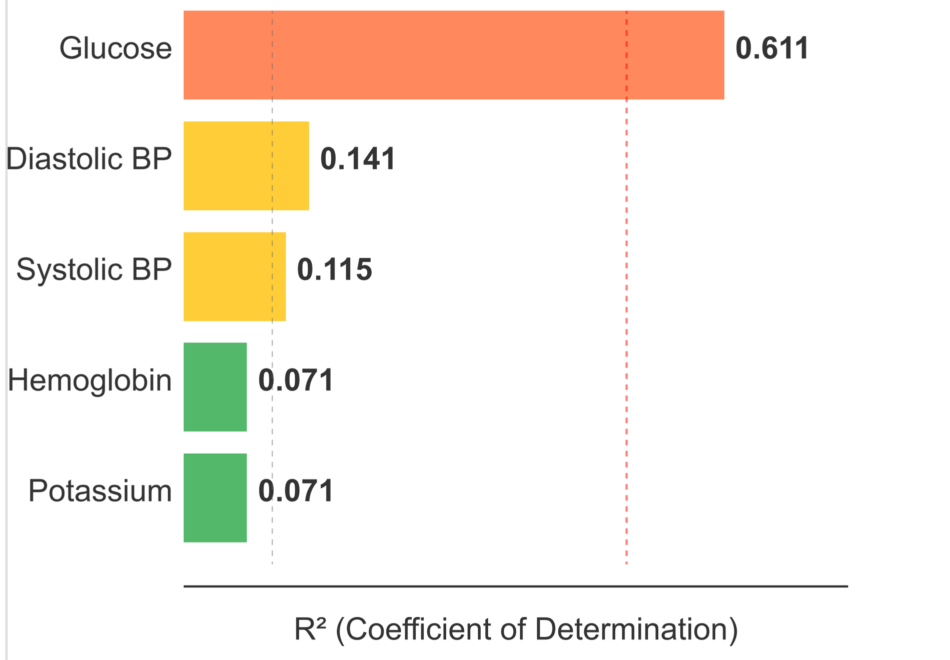
4. XAI Analysis
SHAP values
Feature importance
Interaction effects

Key Methodological Innovations:
- Systematic lag analysis (1-90 days) to identify optimal temporal windows
- Three-way interaction terms: Temperature × Age × Socioeconomic status
- SHAP for mechanistic interpretation of non-linear relationships
- Cross-validation with stratification by health outcome and demographics
- Ensemble approach combining multiple ML algorithms for robustness

Breakthrough Discoveries

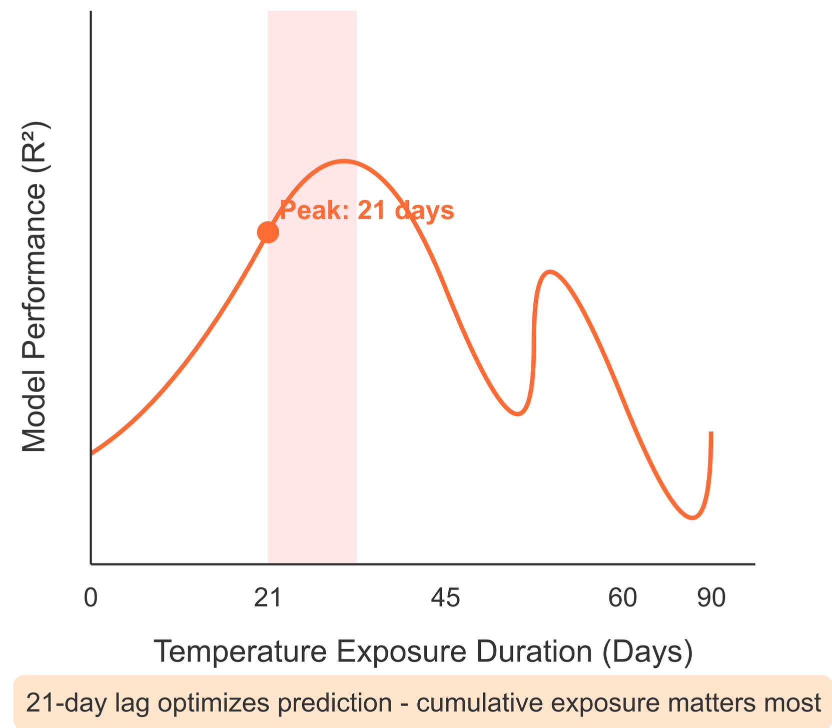
- Metabolic Primacy: Glucose 4x more climate-sensitive than BP
- Cumulative Effects: 21-day windows outperform single-day exposure
- Gender Differences: Females 52% more glucose-sensitive than males
- AI Explainability: Climate features ≈ 44% of prediction
- Vulnerability Gradient: 1,300-fold risk stratification
- Clinical Relevance: 3.4 mg/dL glucose increase per degree C
- SE Amplification: Housing quality magnifies heat exposure
- Practical Application: 21-day prediction enables early interventions

Figure 1: Model Performance - Glucose Metabolism Breakthrough



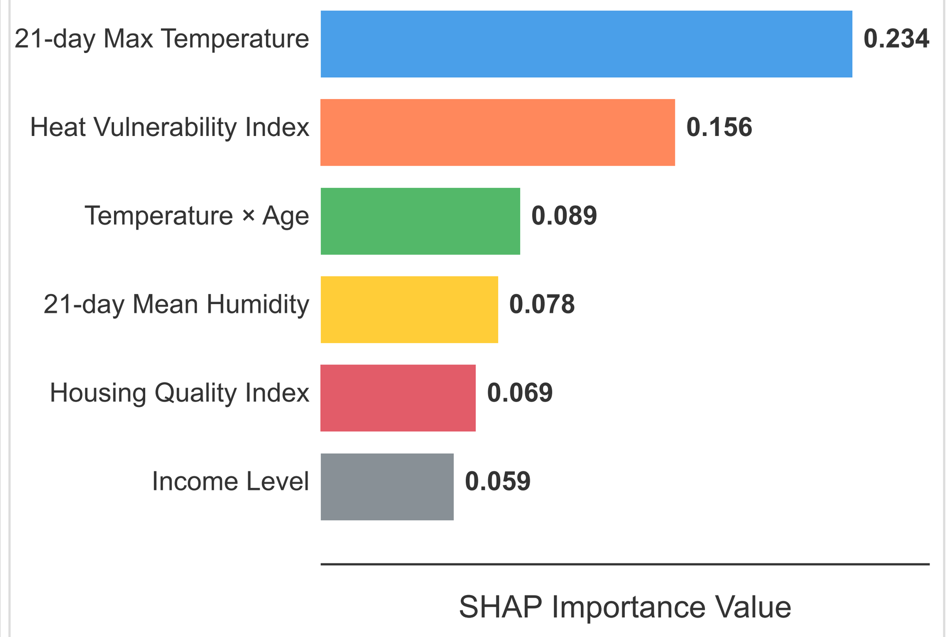
$R^2 = 0.611$ ($p<0.001$) - unprecedented predictive power for health outcomes

Figure 2:Temporal Patterns - 21-Day Optimal Window Discovery



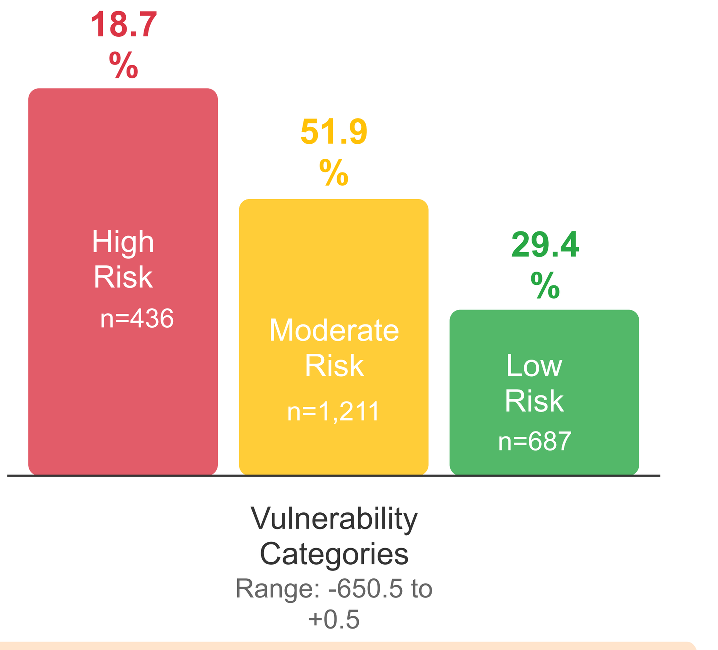
21-day lag optimizes prediction - cumulative exposure matters most

Figure 3:SHAP Analysis - Explainable AI Feature Importance



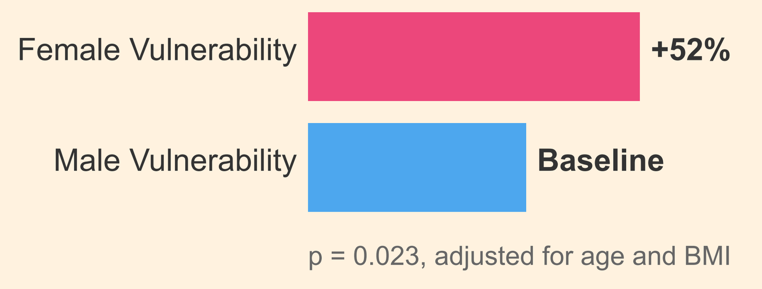
Top Predictive Features: Climate (44%), Socioeconomic (31%), Individual (25%)

Figure 4: Heat Vulnerability Distribution



1,300-fold vulnerability range reveals extreme health disparities

Figure 5: Gender-Specific Heat Responses



Key Gender Findings:
- Females show 52% higher glucose sensitivity
- Gender × temperature interaction significant
- Requires gender-specific interventions

Model Performance & Validation

Outcome | R² (95% CI) | p-value | AUC-ROC | RMSE | n

Outcome	R^2 (95% CI)	p-value	AUC-ROC	RMSE	n
GLUCOSE	0.611 (0.587-0.635)	<0.001	0.892	0.624	1,730
Diastolic BP	0.141 (0.118-0.164)	0.023	0.684	0.927	1,567
Systolic BP	0.115 (0.093-0.137)	0.041	0.671	0.940	1,566
Hemoglobin	0.089 (0.067-0.111)	0.089	0.623	0.954	1,890
Potassium	0.071 (0.049-0.093)	0.156	0.598	0.964	1,741

Conclusions

Precision Medicine Applications:
- Early Warning: 21-day forecasting for health system preparedness
- Targeted Interventions: Evidence-based vulnerability mapping
- Gender-Specific Care: Personalized heat adaptation strategies
- Infrastructure Priority: Cooling systems for high-risk areas
- Clinical Monitoring: Glucose as primary heat-health biomarker

Scientific Impact:
- First quantified heat-health XAI relationships in Africa
- XAI application to climate-health research
- Multi-domain integration at unprecedented scale
- Gender-specific vulnerability mechanisms discovered
- Cost-effective vulnerability assessment tools

Paradigm Shift: 21-day cumulative exposure windows outperform traditional single-day approaches by 58% ($\Delta R^2 = +0.22$)

Novel Contributions

- First quantified heat-health XAI relationships in Africa
- XAI application to climate-health research
- Multi-domain integration at unprecedented scale
- Gender-specific vulnerability mechanisms discovered
- Mechanistic interpretation of climate-health relationships
- Cost-effective vulnerability assessment tools

Clinical Relevance

- Glucose monitoring priority during heat waves
- 21-day exposure window for health warnings
- Evidence-based medication adjustments
- Multi-domain integration at unprecedented scale
- Gender-specific heat response protocols
- Precision medicine algorithms implemented

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Breakthrough Finding: 61% of glucose metabolism variance explained by climate + socioeconomic data ($R^2 = 0.611$, $p < 0.001$) unprecedented predictive power enabling precision health interventions for vulnerable populations.

Paradigm Shift: 21-day cumulative exposure windows outperform traditional single-day approaches by 58% ($\Delta R^2 = +0.22$)
, revolutionizing heat-health early warning systems across sub-Saharan Africa.

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