MI-Environment: Cumulative Environmental Exposure Project
Climate Change Heat Stress Vulnerability Pilot 2015 Final Report and Phase 2 Proposal

The National Academies of Science report, “Science and Decisions: Advancing Risk Assessment,” points to the need for innovative methodologies and tools to consider cumulative environmental exposures in policy (1). California has been a leader in cumulative risk frameworks and has implemented a second version of their cumulative exposure index in the EnviroScreen tool, which serves as a model for our endeavor (2, 3). However, California has not included a climate vulnerability index in the tool that will allocate funding for climate adaptation to localities. As successfully demonstrated by the U.S. Environmental Protection Agency EPA and California, maps can facilitate public engagement with these complex multidisciplinary issues. Researchers are developing methodologies that we wish to explore in the context of Michigan (4). Northern states such as Michigan have a need to characterize climate change related exposures and vulnerabilities, especially regarding heat stress for which the population, infrastructure, and practices may not be well adapted (5). Nevertheless, significant political and technical barriers prevent states such as Michigan from adopting the techniques pioneered in California despite the benefits to sustainability of identifying the areas potentially most vulnerable to climate change and other environmental hazards. Academic and community partners can provide the necessary methods development, data, and impetus for a state to enhance its exposure assessment and thereby facilitate healthier, sustainable communities.

Our pilot project has made great strides in creating an innovative cumulative exposure visualization tool. We established a partnership shown in Figure 1. We completed a first heat stress Geographic Information System (GIS) layer of a larger We assembled readily available underlying data and created heat stress vulnerability indices and maps, including for the first time temperature projections from climate modeling ensembles, that will allow the public to understand the location and relative magnitude climate vulnerability on selected metrics across the state of Michigan. The scholarly aim that motivates our overall interdisciplinary project is to characterize the spatial pattern of cumulative exposures to environmental and social vulnerabilities in Michigan through visualization via GIS tools and thereby to foster improved health outcomes. This pilot phase focused on vulnerabilities to heat stress at the census tract level as one example of a climate change-related human health impact.

Figure 1. MI-Environment Screening Tool: a multi-disciplinary effort blending geography, remote sensing, urban planning, environmental health sciences, climatology, and public policy analysis.

Phase One completed the Heat Stress Vulnerability Layer. Phase Two will complete additional layers using established methods, complete the web platform, and begin method development for new climate change-related vulnerability indices that will advance knowledge and policy.
**Phase Two: Innovative Product Proposal.** Other environmental exposures and hazards, such as air pollution and hazardous materials, are also identified in the atmospheric science, public health, and urban planning literatures as contributing to community vulnerability today and in the future as the climate changes. Although the scientific data that underpins the connection between exposure to a given chemical and adverse health outcomes is determined in isolation, we are all exposed to a mixture of chemicals and other social phenomena that impact our health. This single chemical approach makes sense when determining causation because isolating a single chemical allows for experiments that demonstrate a direct causal link. However, chemical-by-chemical regulatory policy is much like trying to understand a person’s overall nutrition by only studying how many tomatoes a person eats (or how many tomatoes a person eats at dinner, not considering baseline breakfast and lunch exposure). “Dinner tomato exposure” doesn’t tell us much about a person’s overall diet or the most important factors to act upon to improve health. The same is true for environmental hazards; thus, understanding cumulative environmental exposures is a vital need. The MI-Environment tool is the first step toward visualizing cumulative exposures for Michigan and ultimately the upper Midwest region. Our project is developing an innovative, translational instrument to bring scientific data in service to the public in a meaningful, engaged and interactive manner. The tool will distill complex spatial information into an accessible relative index map. The next layer we propose to build examines hazard proximity to sensitive receptors like school children.

**Social Impact.** This project is timely and will have a broad social impact in two areas: current Michigan environmental policy and national climate change preparedness planning. Michigan’s hazardous waste clean-up criteria are in jeopardy for over 300 toxic chemicals. In 2013, the state legislature rescinded the criteria but allowed the Michigan Department of Environmental Quality (MDEQ) to issue a hurried rulemaking in December to re-establish the criteria and they now must update them. The criteria are the targets for clean up of contamination for land on which homes, sports fields, day cares, schools, hospitals and workplaces are built. The MDEQ acknowledges that the re-established clean up criteria used dated science; for instance, they do not consider baseline exposures to the chemicals of concern at a site or cumulative exposures to other environmental contaminants or social vulnerabilities. This GIS tool will fill this gap in our knowledge. Our approach builds from a framework described in the literature (2) and adopted by another state with extensive public input. We are already testing the GIS analysis methods with data for Kent County, Michigan. From a national policy perspective, a state other than California adopting cumulative exposure concepts would be a significant achievement.

We also aspire to situate this in the broader sustainability and equity context of exposures to health impacts from climate change. The Centers for Disease Control and Prevention (CDC) identifies several priority climate change-related health effects in its Building Resilience Against Climate Effects (BRACE) framework (6). BRACE prioritizes additional health endpoints for the MI-Environment climate vulnerability layer. The BRACE framework, in turn, could be strengthened by methods to consider the baseline cumulative exposure context.

**Next Steps.** We propose to build on our initial success in three parts:
1) Complete the Heat Stress Vulnerability index, conduct equity analysis and comparison with other techniques;
2) Assemble the Hazard Proximity index;
3) Begin to develop methods for other climate change-related vulnerabilities and exposures.

![Figure 2. Center For Disease Control and Prevention framework for human health impacts from climate change.](image-url)
We propose to achieve the three goals with the following objectives:

1) **Refine the Heat Stress Vulnerability Index**
   a) Further refine the heat stress and social vulnerability index. In phase one, we used generally available data; however, with UM Climate Center’s committed support, we will be able to more closely match the projects we seek to replicate in a second phase with additional, specialized climate modeling outputs, such as projected monthly max temperature and number of warm nights.
   b) Determine the extent of any racial, ethnic or socioeconomic disparities in these exposures and susceptibilities. We will refine the demographic data collected and apply chi-square statistical tests.
   c) Quantitatively compare the results of the available indices (e.g., MI-Environment v. the replication of Cal-EnviroScreen v. Reid et al. indices). We will use Pearson rankings and other geospatial techniques to compare rankings within Michigan as well as qualitatively compare with California.

2) **Assemble the Hazard Proximity Index**
   d) Assemble data and replicate Berkeley criteria (2) and Cal EnviroScreen criteria as described below for Heat Stress Vulnerability. This layer will be more data intensive and require more extensive geoprocessing than the pilot. We will assess hazards from the Sadd et al. paper plus major roadways within the sensitive population receptor of K-12 schools, daycares, hospitals and residential areas. We will also analyze within 1,000 to 3,000 meters of the receptor areas. Hazards assessed will include the following: industrial facilities (EPA’s Toxic Release Inventory); auto paint and body shops; fuel stations and permitted hazardous waste treatment storage and disposal facilities (MDEQ data); refineries; intermodal distribution facilities, major railways, marine ports, airports and major roads (U.S. Department of Transportation (DOT) data).
   e) Determine the extent of any racial, ethnic or socioeconomic disparities in these exposures.
   f) Disseminate results via web-based MI-Environment tool. Upgrade the tool from its current prototype status in CartoDB (http://cdb.io/1LegNUU). We will examine the Cal EnviroScreen and the iHeat platforms (7). We propose to use CartoDB in conjunction with Leaflet using JavaScript to build a scalable, interactive open source web platform. Although ESRI’s ArcGIS was our main analytic software, open source software grants greater flexibility and access to underlying data.

3) **Begin to Develop New Methods Related to Climate Change Effects**
   g) Scope out new techniques to create additional community vulnerability indices to estimate relative climate change-related human health exposures. We intend to follow the BRACE framework to focus on precipitation and temperature effects, such as water-borne illness, vector-borne illness, injuries related to flooding and the aftermath of flooding. This step will require precipitation outputs from the climate ensemble modeling and additional processing of those model outputs. The expected outcome is a literature review and proposed methodology.
   h) Evaluate the extent of connection between opinions of local government leaders and degree of vulnerability of communities by linking social science data to our physical and social variables, such as the ClosUp surveys of local government and public opinion about climate change and the role of government in environmental protection. This step will require additional IRB approvals that would be part of the task. Data assembly and exploratory regression analyses would be performed.

Our long-term goal is to engage the public in citizen science to use local knowledge to validate geospatial locations and to expand climate change vulnerability exposures. Our conceptual model can be replicated in other states, especially other upper Midwest states in the climate modeling domain. Our partners have opportunities with other programs such as Tennessee State University faculty who are developing curricula for colleges across the country related to geospatial analysis.

**Strong Partnerships.** Our project partners contribute to a strong likelihood of success of the endeavor as we build long-term relationships of mutual capacity-building ultimately to complete the 5 additional data layers. Our technical and community partners have agreed to continue to mentor
students and provide data, as described in the attached letters. The Michigan Technological Research Institute (MTRI) will assist with technical troubleshooting and a review of the methodologies from the point of view of scientists and GIS experts skilled at creating accessible and rigorous scientific products. UM Climate Center (GLISA) will continue to provide climate model ensemble output data and assist with its incorporation and interpretation. We are building on deep partnerships from many years that the NIEHS-funded Community Outreach and Engagement Core (COEC) has developed with organizations like Detroiter's Working for Environmental Justice (DWEJ, which serves on their board) and that these groups have in turn with their constituents. The COEC is an academic-community partnership, and they are geared to support these types of collaborations and stand ready to support our project. Our community partners will amplify the project's impact in the local community and beyond because these topics are part of their overall mission.

Phase One Results. The shared purpose of the collaboration is to aid in public discourse, education and decisions about environmental health and sustainability in Michigan. In the first phase, we replicated and expanded upon California's EnviroScreen v2 and analyses by Dr. Morello-Frosch at the University of California at Berkeley. We also examined techniques developed by Dr. Marie O'Neill and other scholars for the State of Michigan Department of Health and Human Services (MDHHS). We successfully created a heat stress vulnerability mapping tool that ranks each Michigan census tract relative to each other using techniques successfully in use in California. We also developed a prototype web-based platform that avoids the barrier of needing expensive software licenses to access the data. Working with our partners, in July we introduced our results to the COEC Stakeholder Advisory Board, comprised of environmental health leaders from throughout southeast Michigan. We also were able to feature our maps at the Detroit Climate Action Collaborative public health workshop in August. A panel in which we will feature our mapping tool was accepted to a statewide public health conference this fall. We were able to achieve our objectives with pilot funding for 6 weeks of full-time graduate student effort by catalyzing significant in-kind support from partner organizations. We seek to carry forward this momentum into a second phase.

Phase One Data, Methods and Results Summary

As shown in Figure 3, we achieved two specific analytical objectives for the pilot phase of the project:

1. Replicate as closely as possible the two California analyses using readily available public data:
   a. Cal EnviroScreen v. 2 (3) and
   b. UC Berkeley Criteria (8);
2. Building from learning in objective one and the literature, create a Michigan-specific heat exposure vulnerability index that will link with future elements in the MI-Environment tool.

The Cal EnviroScreen tool does not yet include a heat stress vulnerability layer; however, our project hypothesizes the method the Cal EnviroScreen would use to incorporate such an exposure layer. The Cal EnviroScreen method assembles exposure indicators and then multiplies the results of those layers at the census tract level by social vulnerability. The rationale is that there is a multiplicative effect of the social vulnerabilities. In essence, this analytical choice magnifies the effect of poverty and other elements of social vulnerability. By contrast, the Berkeley criteria averages social vulnerability, and the other layers in its complete form.

Figure 3. Comparison of three approaches
For our replication of the two California analyses of Climate Vulnerability Heat Stress layer, we started with the same heat stress exposure layer from the Berkeley criteria, and then we processed the data differently. The Berkeley criteria has not yet been published, but it is based on a presentation of preliminary results by Dr. Rachel Morello-Frosch (9). The heat stress exposure layer is comprised of seven different indicators grouped into three areas: heat island exposure; temperature; and social isolation/mobility/susceptibility to heat stress. In this replication project, we made some adjustments based on data availability for Michigan as detailed in Figure 4. Accordingly, for both replications, we start with the equally weighted 3-indicator index Berkeley Criteria to Michigan, as shown in Figure 5.

To replicate the Cal EnviroScreen method, we first assemble an exposure layer using the Berkeley criteria. We then multiply the exposure index by social vulnerability. We then made additions for the MI-Environment Michigan-specific analysis.

**Figure 4. Comparison of Four Methodologies: Original California Analyses, Replication in Michigan of California EnviroScreen Criteria, Replication in Michigan of Berkeley Criteria, and MI-Environment Michigan-Specific Analysis**

<table>
<thead>
<tr>
<th>Index Grouping</th>
<th>Summary of Cal EnviroScreen and Berkeley Model</th>
<th>MI-Environment Replication I. Cal EnviroScreen Criteria</th>
<th>MI-Environment Replication II. Berkeley Criteria</th>
<th>MI-Environment III. Michigan-Specific Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A1. Heat Island Exposure</strong></td>
<td>% Tree canopy coverage (National Landuse Cover Database (NLCD) 2001) (10)</td>
<td>% Tree canopy coverage (NLCD 2011) (11)</td>
<td>% Tree canopy coverage (NLCD 2011) (11)</td>
<td>% Tree canopy coverage (NLCD 2011) (11)</td>
</tr>
<tr>
<td></td>
<td>% Impervious Surface (NLCD 2001) (10)</td>
<td>% Impervious Surface (NLCD 2011) (11)</td>
<td>% Impervious Surface (NLCD 2011) (11)</td>
<td>% Impervious Surface (NLCD 2011) (11)</td>
</tr>
<tr>
<td>Heat Island Exposure Index (CalEnviroScreen, Berkeley, and MI-Environment criteria)</td>
<td>((Canopy Index) + (ImperviousIndex))/2*100</td>
<td>Could not obtain data</td>
<td>Could not obtain data</td>
<td>N/A</td>
</tr>
</tbody>
</table>

| | Number of projected hot days (over 90 degrees Fahrenheit or 32.2 degrees Celsius) (2041-2070) | Number of projected hot days (over 90 degrees Fahrenheit or 32.2 degrees Celsius) (2041-2070) | Number of projected hot days (over 90 degrees Fahrenheit or 32.2 degrees Celsius) (2041-2070) | Number of projected hot days (over 90 degrees Fahrenheit or 32.2 degrees Celsius) (2041-2070) |
| Temperature Exposure Index (CalEnviroScreen and Berkeley criteria): | ((HeatDay_Index) + (TempChange_Index))/2 | Temperature Exposure Index (MI-Environment criteria): | (75*HeatDayIndex) + (.25*Avg Seasonal Temp Index) |
### A3. Social Mobility/Isolation/Susceptibility

<table>
<thead>
<tr>
<th>% elderly living alone (2005-2009)</th>
<th>% of the population older than 65 years and living alone (2012 ACS data)</th>
<th>% of the population older than 65 years and living alone (2012 ACS data)</th>
<th>% of the population older than 65 years and living alone (2012 ACS data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Social Mobility/Isolation Index (CalEnviroScreen and Berkeley criteria): \(65\text{aloneIndex} + \text{NocarIndex}\)/2  
Social Mobility/Isolation Index (MI-Environment criteria): \(65\text{aloneIndex} + \text{NocarIndex} + \text{ObeseIndex}\)/3

### B1. General Social Vulnerability

<table>
<thead>
<tr>
<th>% of population over age 65 (2010 U.S. Census)</th>
<th>% of the population older than 65 years and living alone (2012 ACS data)</th>
<th>N/A *</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>% living two times below federal poverty level (2008-2012 ACS)</td>
<td>% of the population living below federal poverty level (2012 ACS)</td>
<td>N/A *</td>
<td>% of the population living below federal poverty level (2012 ACS)</td>
</tr>
<tr>
<td>% of population under age 10 (2010 U.S. Census)</td>
<td>% of children under 5 years (2012 ACS data)</td>
<td>N/A *</td>
<td>% of children under 5 years (2012 ACS data)</td>
</tr>
</tbody>
</table>

Sensitive Populations Index (CalEnviroScreen criteria): \(65\text{aloneIndex} + PovIndex + Under5Index\)/3  
Sensitive Populations Index (MI-Environment criteria): \(PovIndex + Under5Index + Alone65Index\)/3

* In the broader 5-part index, Layer B1 would be averaged with the other exposures. Thus, we omitted this layer in our replication due to concerns about double counting.

### Aggregated Indices

Agg Index (CalEnviroScreen criteria): \([(\text{Heat Island Risk Index} + \text{Temperature Exposure Index} + \text{Social Mobility/Isolation Index})/3]\) * Sensitive Population index  
Agg Index (Berkeley criteria): \([(\text{Heat Island Risk Index} + \text{Temperature Exposure Index} + \text{Social Mobility/Isolation Index})/3]\)  
Agg Index (MI-Environment criteria): \([(\text{Temperature Exposure Index} + \text{Heat Island Risk Index} + \text{Social Vulnerability Index})/3]\) * [Sensitive Populations]

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Our resulting replication of the UC-Berkeley criteria in Figure 5 shows the relative exposures and vulnerabilities of communities to heat stress at the census tract level. However, not all input data were available at that fine a scale, as discussed in detail in our draft manuscript. In particular, a key limitation is the lack of finer scale climate ensemble data, which was available at the 10 climatic divisions in Michigan. In addition, the available climate models do not predict lake effects well, even if more detailed geographic output were available.

In Figure 6, we also present a MI-Environment Michigan-specific index that uses Figure 5 as an input, adds obesity prevalence, and multiplies by social vulnerability. Obese individuals are more susceptible and possibly vulnerable to heat exposure compared to other adults (Koman and Gronlund, forthcoming). The National Institute of Health (NIH) defines obese as body weight of 30kg (66 lbs)
Relative Heat Vulnerability Exposure by Census Tract

Aggregated Index
1
2
3
4
5 high

over ideal body weight or a body mass index (BMI) of 30 kg/m² or greater. Similarly, NIH defines "overweight" as adults with a BMI of 25 – 29.9 kg/m². Over two thirds of adults nationwide are obese or overweight (14). Michigan has a high percentage of obese adults (31.5% in 2013), and these data were available at the county level. Similar to Cal EnviroScreen, the final step is to multiply by social vulnerability.

In our second phase, we are proposing some specific extensions for the heat vulnerability outcomes. We would seek to refine the climate modeling temperature data, assess the extent of racial disparities in these outcomes, and compare our technique with other approaches. We are also interested in linking these maps with surveys of local officials and the public. We would refine our web platform for disseminating the results.

Key milestones. The three-part project assumes 4 graduate students for 10 weeks full-time effort mainly over the summer, with potentially part time hours during the academic term to initiate the work and complete final reports and proposals. The timeline consists of three periods:

Period 1: Framework and work plan development: First 25 days. Graduate student interns will be hired and oriented. With advice from faculty mentors, the student team will develop a draft framework, GIS flow diagram, and work plan. Partners will review these. All will participate in kick-off meeting.

Period 2: Data gathering, analysis and map layer creation: Next 6 weeks. Parts 1 and 2 Student interns will gather available data, assemble data layer and create options for analyses and display. Methods will be developed and analyses performed. A mid-term conference call will be held to gather additional feedback from partners. Student interns will document analyses in manuscript and technical report. The student interns will develop the web-based platform and upload data and indices. Part 3 students will perform literature review, develop a proposed methodology, and gather initial data for proof of concept testing.
At the completion of the project, the project manager will store the final products. A final meeting will be held to discuss project outcomes, evaluation, and next steps.

The MI-Environment project also has the potential to align with and strengthen other proposals submitted for the Dow Interdisciplinary Award, especially the proposal submitted by Missy Stults and colleagues. Our web-based platform and data could be designed to be accessible by the widget envisioned in that project to help local communities and state-wide partners to understand an area’s relative vulnerability and thus need to build resilience and sustainability.

**Personnel.** **U-M Faculty Mentor:** Associate Professor Marie O’Neill, University of Michigan (U-M), School of Public Health (SPH), Environmental Health Sciences Department (EHS)

**U-M Student Members:**
- Meredith Burke, undergraduate senior, Literature, Sciences and Arts (LSA)
- Patricia Koman, MPP, PhD candidate, SPH, EHS and team point of contact (tkoman@umich.edu)
- Susan Landfried, MUP candidate, Taubman College of Architecture and Urban Planning (TCAUP), Department of Urban Planning
• Kyu Han Lee, MPH, PhD candidate, SPH, Department of Epidemiology
• Frank Romo, MUP candidate, TCAUP, Dept. of Urban Planning, and Dow Sustainability Fellow

Partner Organizations:
• Dr. Nancy French, Michigan Technological Research Institute (MTRI)
• Dr. Chris Coombe, Research Faculty, University of Michigan NIEHS Environmental Health Sciences Core, Community Outreach and Engagement Core
• Ms. Kimberly Hill Knott, Detroitors Working For Environmental Justice
• Ms. Donele Wilkins, Executive Director, Green Door Initiative
• Ms. Beth Gibbons, University of Michigan Climate Center

Additional Advisors:
• Dr. Robert Goodspeed, Assistant Professor, TCAUP, Department of Urban Planning
• Dr. Carina Gronlund, Post-doctoral Researcher, UM SPH, Department of Epidemiology, and Dow Sustainability Fellow alumnae

Phase 2 Budget: $50,000 Total

$44,240  Labor for 4 graduate student interns
        Masters student: $18/hr plus 9.71% FICA/benefit recharge ($19.74/hr) @ 40
        hours/week = $790/week for 14 weeks is $11,060 x 4 students = $44,240

$425  4 External hard drives to back up data
$500  Poster printing, office supplies (color printing)
$450  Travel for visits to community partner or data providers
$400  Honoria for community partners
$300  Supplies for community engagement events
        (marketing, activity supplies, and hosting)
$3,685  Hosting on-line web-base mapping

The full budget envisions 4 graduate student interns who would work as an inter-disciplinary team with approximately these responsibilities, depending on the specific skills of the available students:

Part 1: 1 student to focus on heat vulnerability, racial disparities analysis and report writing (returning geospatial analyst from phase one)
Part 2: 1 – 2 students to work on hazard proximity layer and web-based tool (continuation of one geospatial urban planning analyst from Rackham Arts of Citizenship pilot project)
Part 3: 1- 2 advanced graduate student with statistics preparation and a social sciences background to prepare IRB documents, add the ClosUp survey data, statistically compare methodologies and analyze various mapping techniques as well as contribute to new methods for other climate change-related human health outcomes (PhD student from phase one and additional student)

A $25,000 budget could reduce the number of graduate student interns to 2 students, reducing the expected objectives to the first three presented on page 2 of the proposal.

Contact: Trish Koman 734-764-0552  tkoman@umich.edu
References


9. Morello-Frosch RA. Moving Upstream to Address Environmental Justice: Cumulative Impacts Assessment and Implications for Policy. Heal Equity Speak Ser Ann Arbor, MI: 2015.


