Urban Growth Modeling: Phoenix Metropolitan Statistical Area

Lechuan Huang: hlechuan@upenn.edu
Zihan Zhao: zihanzhao@upenn.edu
May 8th, 2022

1. Introduction

It is necessary for planners to analyze future urban land planning and development through the changing trend of urban land planning in the past. At the same time, forecasting the development trend of urban land planning has an important guiding role for stakeholders in various industries. For example, for planners, this urban land planning forecast will guide them to put forward proposals that are more conducive to development. For municipal managers, the forecast report will help them understand the laws and restrictions of urban land cover development, which will help them make decisions. For real estate developers, this forecast can coordinate them to maximize their profit. Finally, for families, this forecast is helpful for their future family investment plans and asset management.

It is necessary to establish a reasonable and reliable model to predict future land cover changes by obtaining open data on past urban development and related factors. This project will build a binary linear regression model for urban land development changes from 2009 to 2019 based on the open data (land cover, land cover change, demographics, and highways system) of three counties (Gila, Maricopa, and Pinal) in the Phoenix metropolitan area. The model will forecast land cover, demand, and development in 2029. This binary linear regression model assumes that the urban growth trend in the next ten years is similar to the previous ten years.

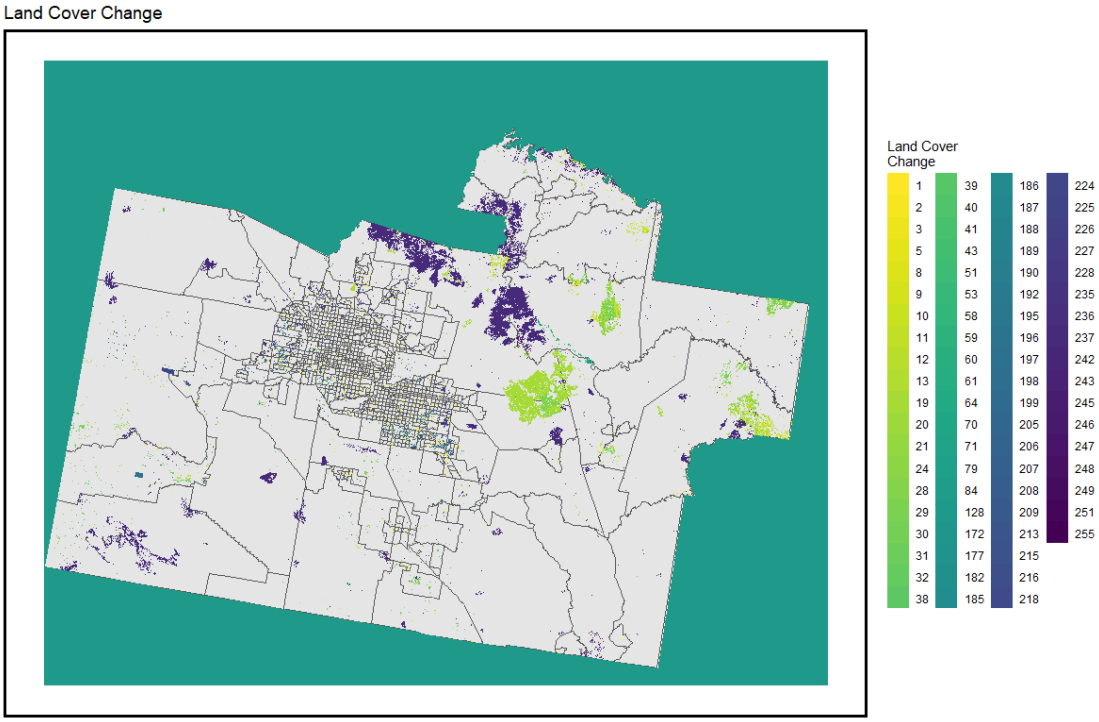
This project will use the above method to forecast the urban growth of Phoenix in 2029. The City of Phoenix is located in the southern part of Arizona, and it is one of the largest cities by population in the United States. Phoenix has a typical hot desert climate because of its proximity to the Sonoran Desert. Year-round high temperatures and long sunshine hours make this city very little precipitation. But despite this, with the entry of some high-tech companies and industrial development after World War II, Phoenix gradually developed

into a thriving cultural and economic center in the desert. After the millennium, the local government of Phoenix has been working towards a thriving, healthy, and environmentally friendly community-based vision, and new urban planning around these interests. After the Great Recession of 2007-2009, Phoenix's long-term population and economic conditions slowly recover. The geographic scope of this project is three counties near Phoenix: Gila, Maricopa, and Pinal. Maricopa County and Pinal County define the Phoenix metropolitan area, also known as Phoenix-Mesa-Scottsdale Metropolitan Statistical Area (Phoenix MSA).

2. Data Wrangling

2.1. Land Cover Change

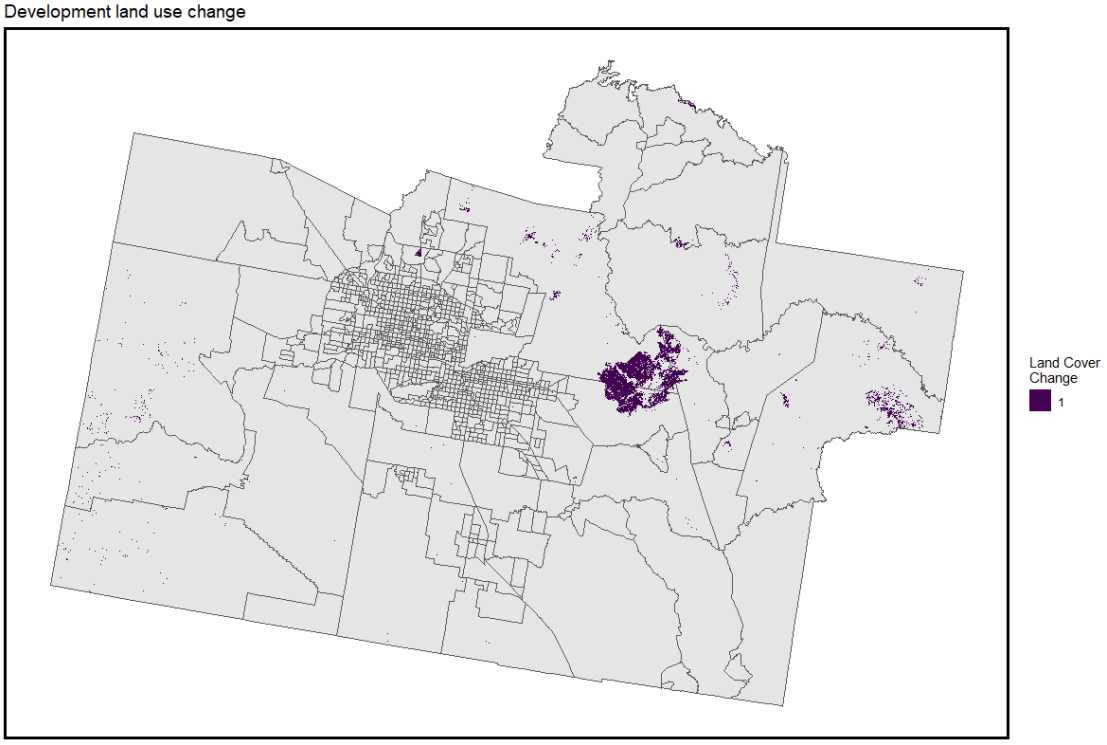
First, download the Phoenix MSA boundary data and the 2009-2019 land cover change data. The Phoenix MSA boundaries shapefile data was downloaded by tidycensus package. The land cover change data was retrieved from USGS ScienceBase Catalog. Then create the land cover change map.



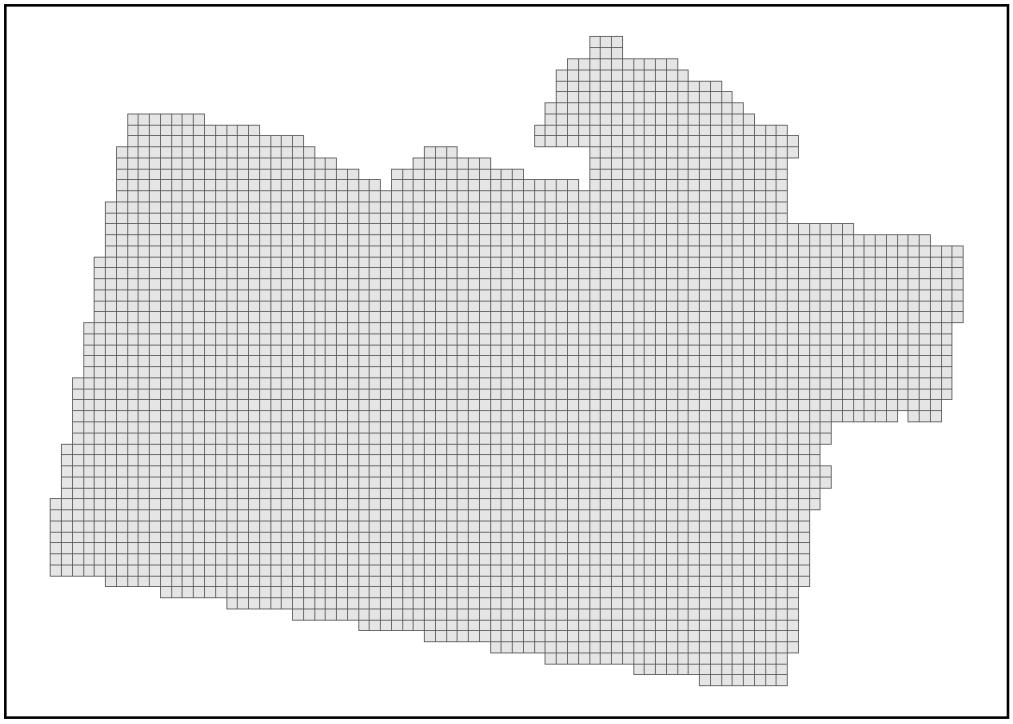
National land cover data was clipped by Phoenix MSA shapefile and sampled

to a vector fishnet so that the other data could later join it. The land cover type data were reclassified into "developed" and "undeveloped" categories. The developed grid cells receive a value of 1, and all others receive a value of 0. Since this is the land cover change data, the cells with a value of 1 indicate the areas that changed from undeveloped to developed.

Development land use change



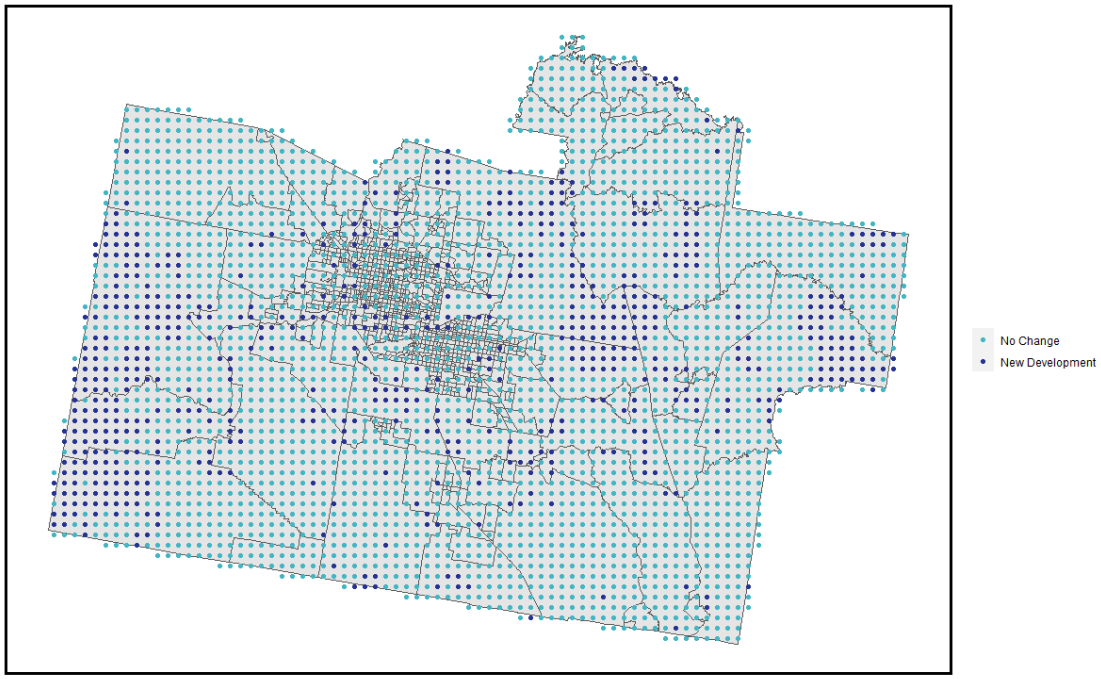
Fishnet, 4000 foot resolution



2.2. 2009 Land Cover Data

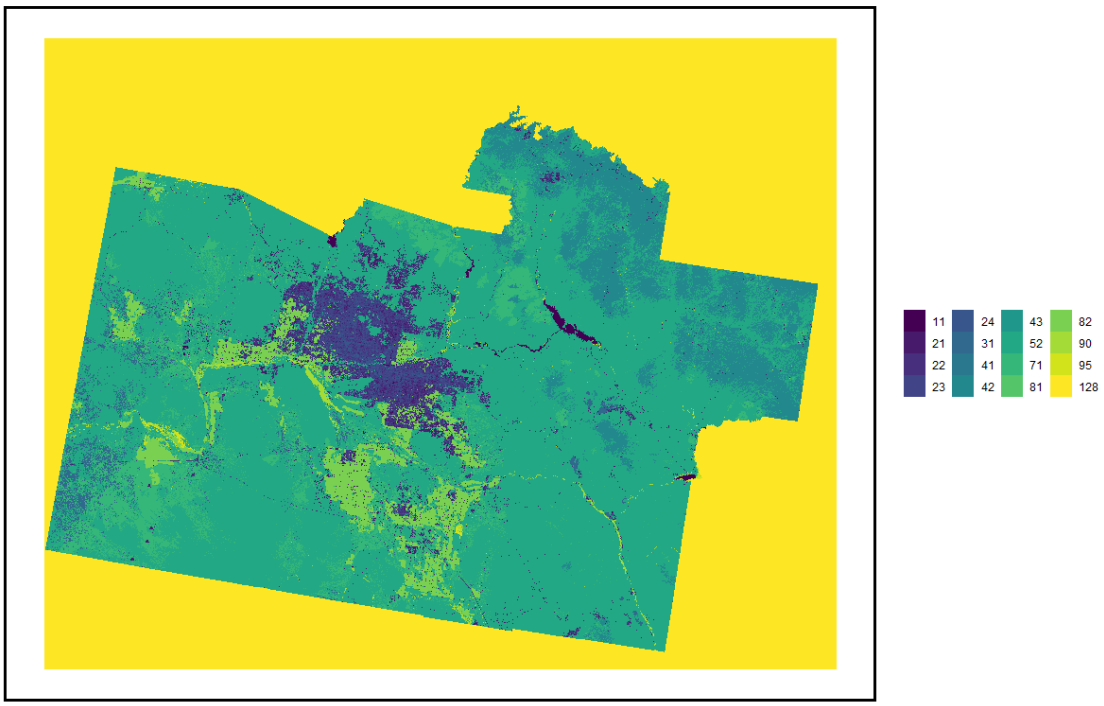
Land cover development change

As fishnet centroids



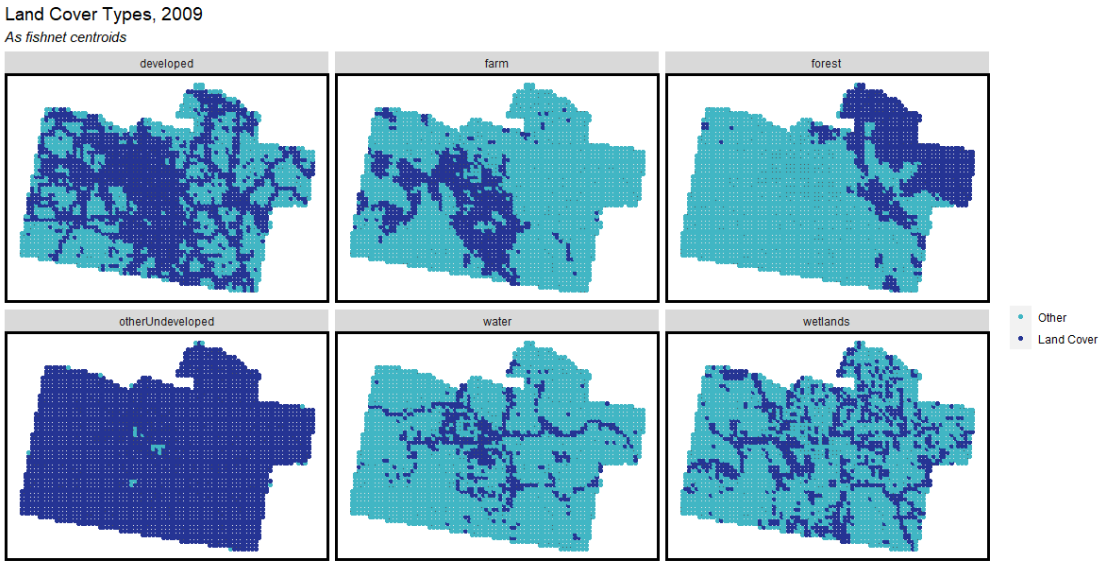
Next, we wrangle, and plot the 2009 land cover data, then integrate it with the fishnet.

Land Cover, 2009



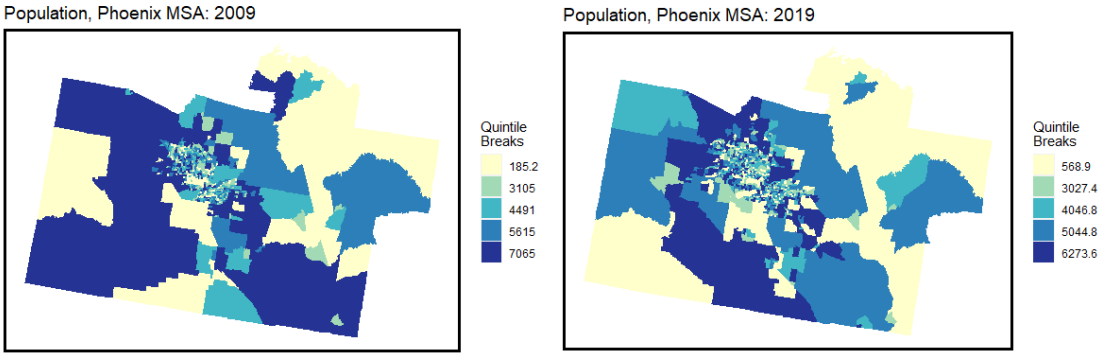
The table below shows the approach taken to recoded existing land cover codes into the categories used in our analysis. The maps below show reclassified land cover types data in 2009.

Old_Classification	New_Classification
Open Space as well as Low, Medium and High Intensity Development	Developed
Deciduous, Evergreen, and Mixed Forest	Forest
Pasture/Hay and Cultivated Crops	Farm
Woody and Emergent Herbaceous Wetlands	Woodlands
Barren Land, Dwarf Scrub, and Grassland/Herbaceous	Other Undeveloped
Water	Water

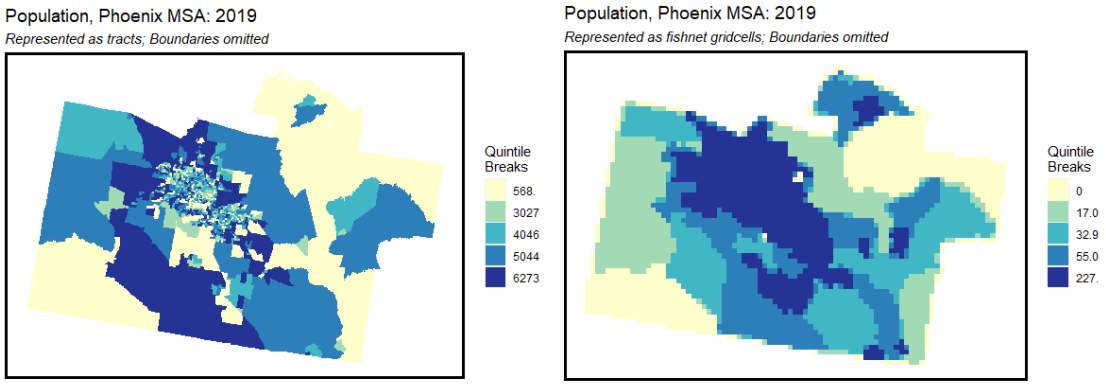


3. Census Demographics

Since the Great Recession in 2009, Phoenix's economy has gradually recovered, which has also brought about a gradual increase in population. Therefore, the change of regional population data in ten years is also essential for this project to study land cover change. Census data for both 2009 and 2019 can be downloaded from the tidycensus package. The following is a map of population distribution in 2009 and 2019 of Phoenix MSA.



Then this project completed population-weighted grid cells in 2019 with the areal weighted interpolation technique to avoid assigning the same population value from one area to many intersecting grid cells.



4. Highway Distance & Spatial Lag

The highway system is an indispensable transportation resource for urban development, which determines the accessibility of urban land development projects. National Highway System data (NHS) were downloaded from Arizona Open Data. To study future urban land development trends, this project studied the distances of various parcels in fishnet to highway arterials and plotted them as follows.

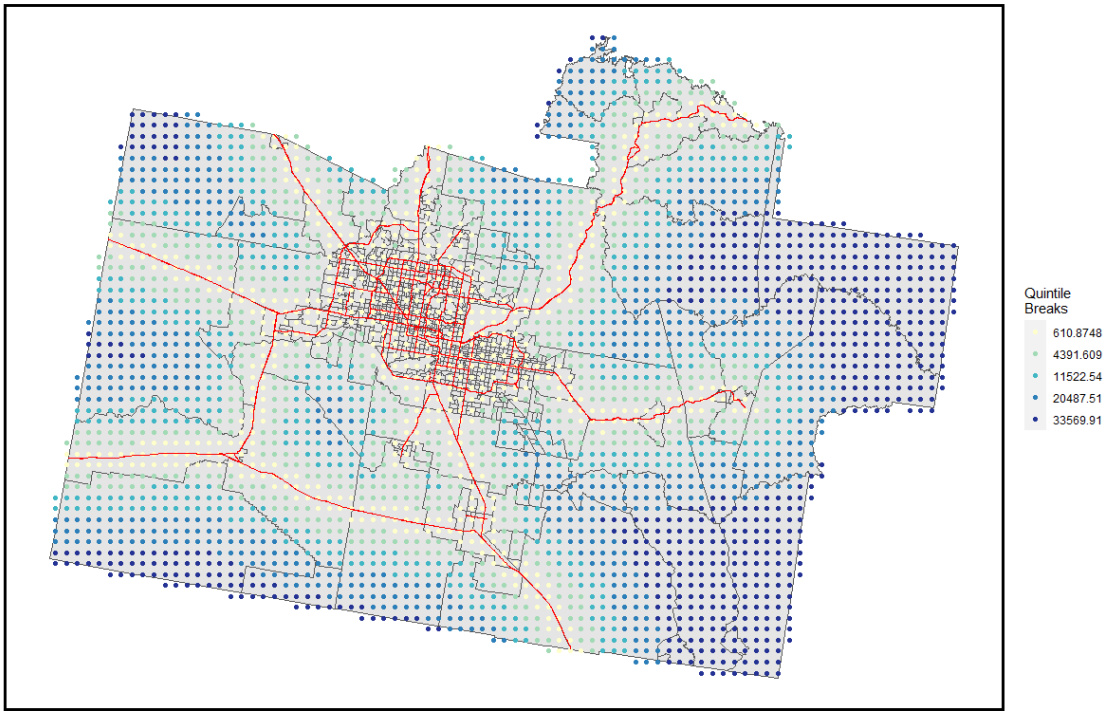
New Development and Highways

As fishnet centroids

To measure accessibility, the distance from each fishnet grid cell to its nearest highway segment is calculated.

Distance to Highways

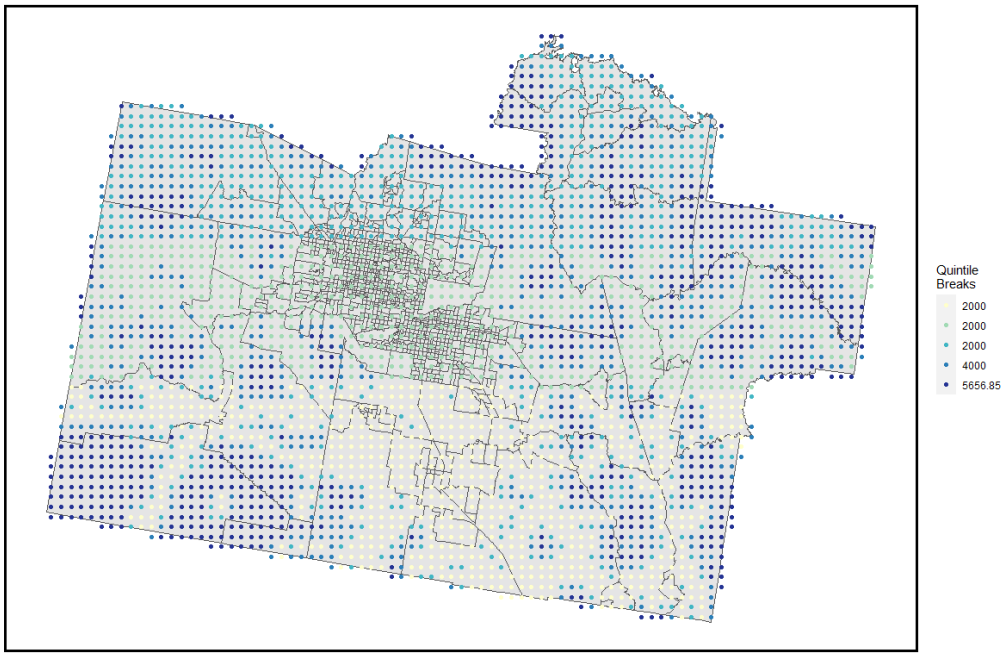
As fishnet centroids; Highways visualized in red



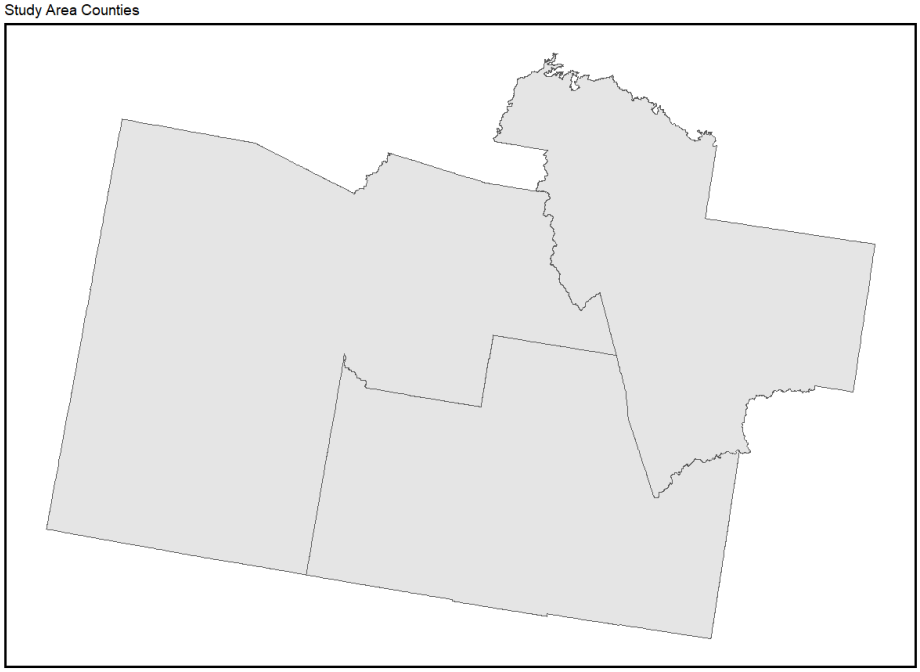
Arizona is dry all year round, so regional development is even more difficult in the harsh conditions of the natural environment. Therefore, the urban development of Phoenix is inseparable from the considerable potential brought by the developed area. To measure accessibility between developments, we also calculated the average distance from each fishnet grid cell to its two nearest developed neighboring grid cells in 2009.

Spatial Lag to 2009 Development

As fishnet centroids



Study Area Counties

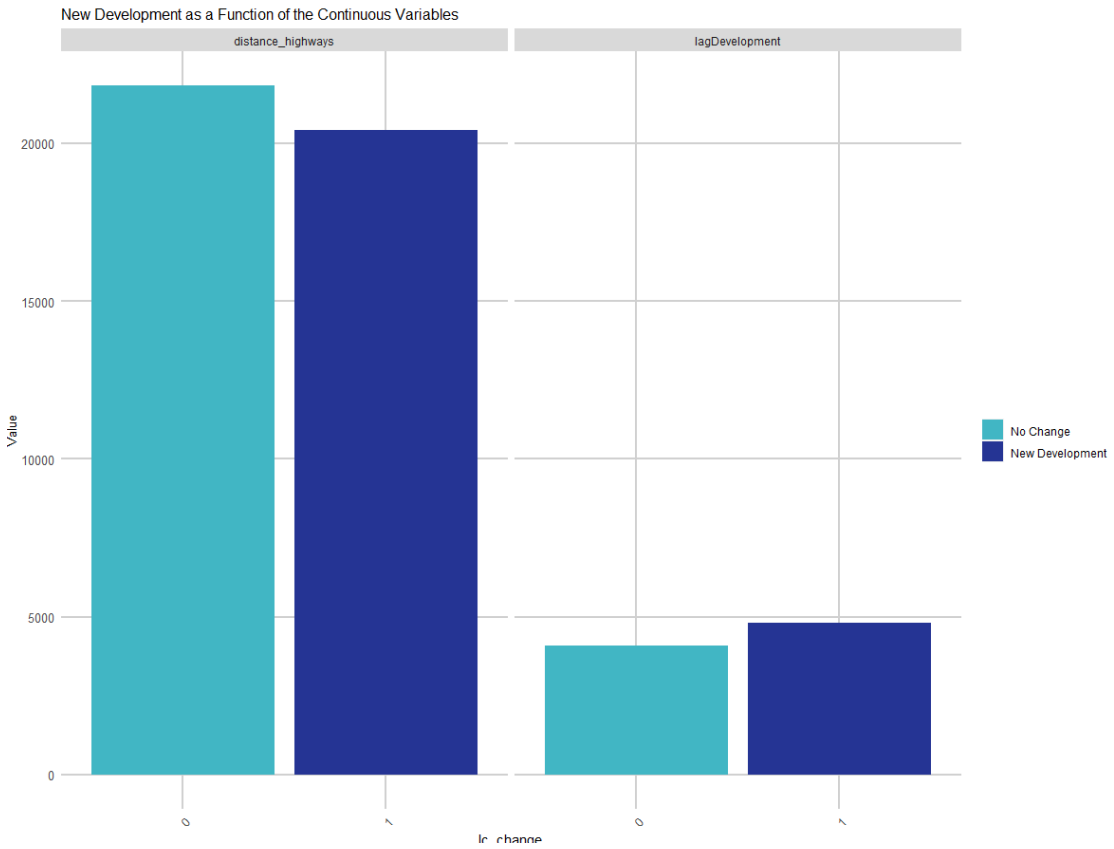


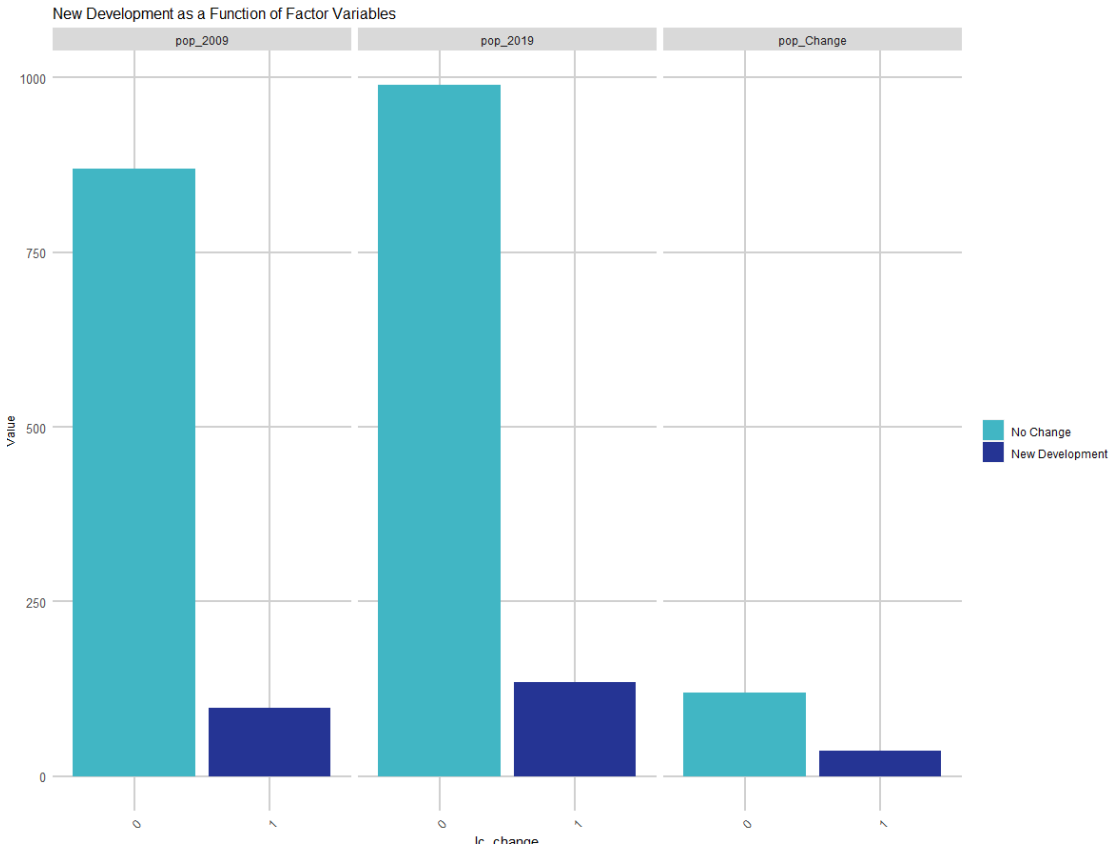
Phoenix MSA county boundaries shapefiles were downloaded using the tigris package. This will be used in later county-level analysis. Now all the feature layers are gathered into one dataset.

5. Exploratory Analysis

In this section we explore the extent to which each feature is associated with development change.

The below bar plots indicate that compared to undeveloped grids, developed grids are nearer to highways and existing developments. Accessibility is critical for urban development of new plots.



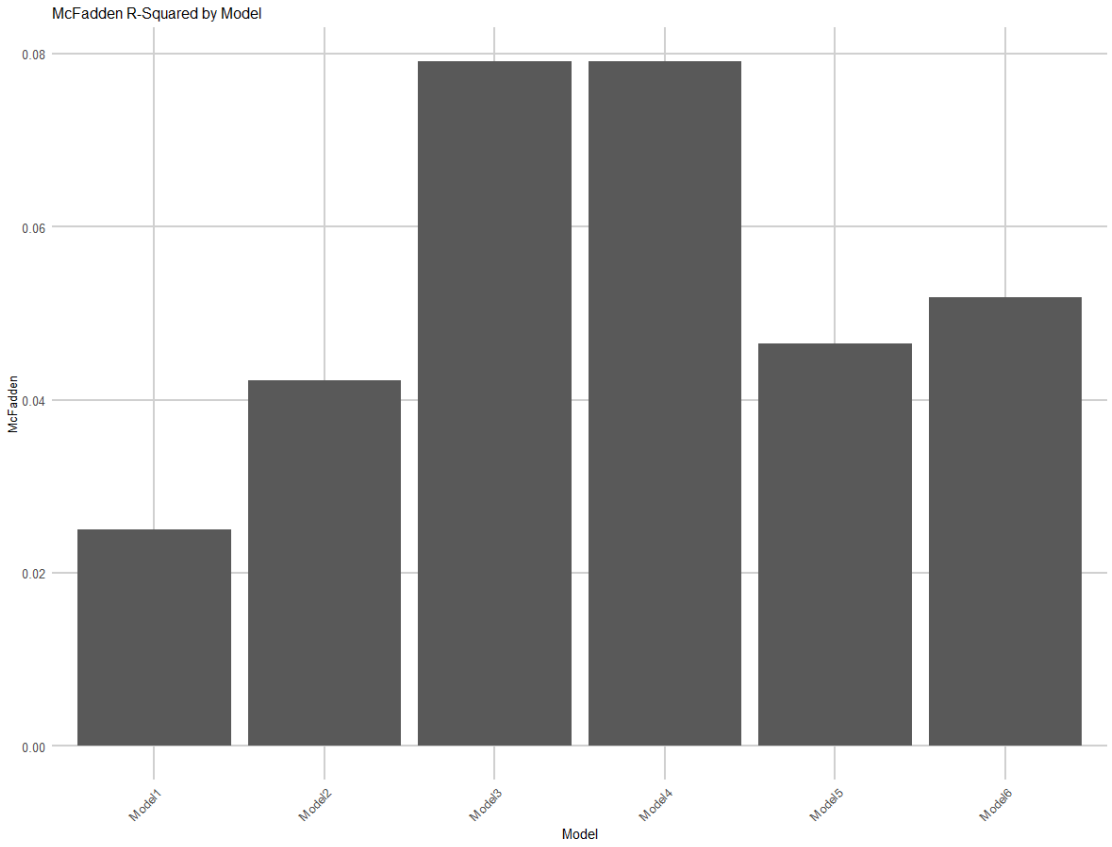


Land_Cover_Type	Conversion_Rate
developed	3.94%
farm	1.55%
forest	3.01%
otherUndeveloped	8.53%
wetlands	2.68%

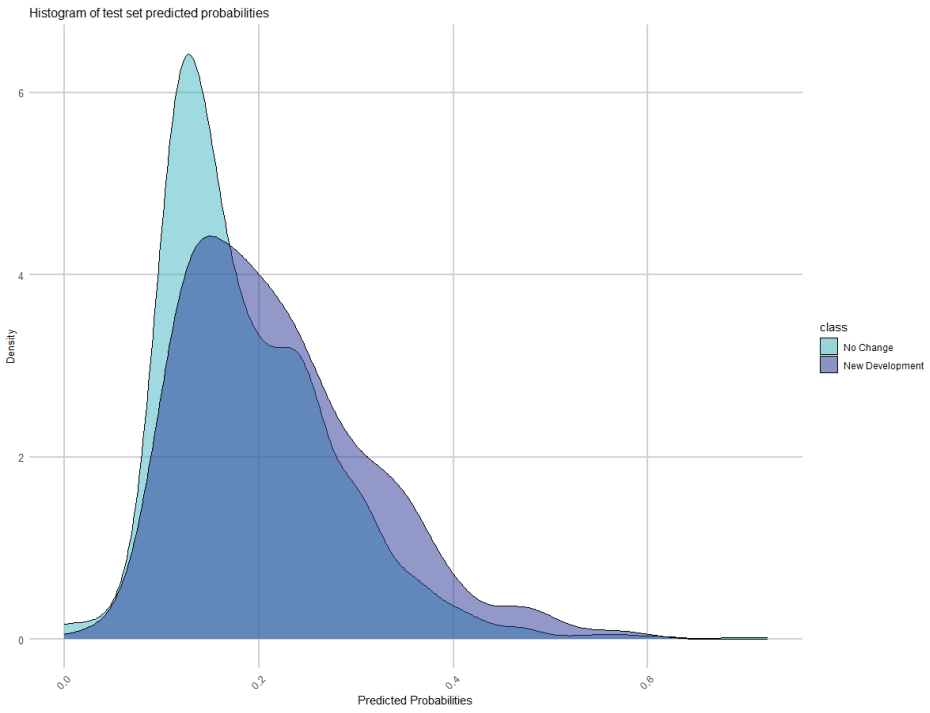
6. Prediction for 2029

6.1. Modeling

Six logistic regression models were tested on the dataset. Model4, which uses 2009 land cover types, spatial lag development, and population of 2009 and 2019 had the highest McFadden R-Squared value. Therefore, model4 was employed for final prediction.



Output the predicted probability of a test set fishnet cell being developed by using the model4. The below histogram visualizes the distribution of predicted probabilities by observed classes: “no change” and “new development”.

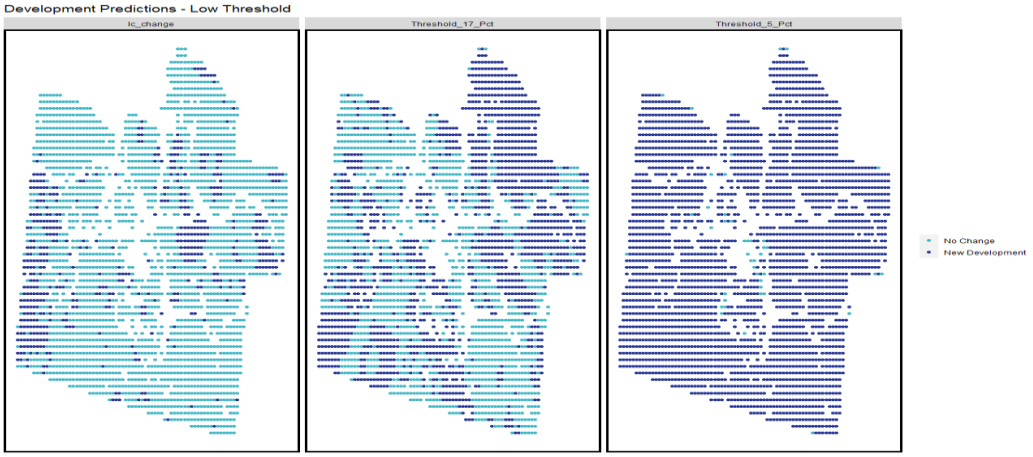


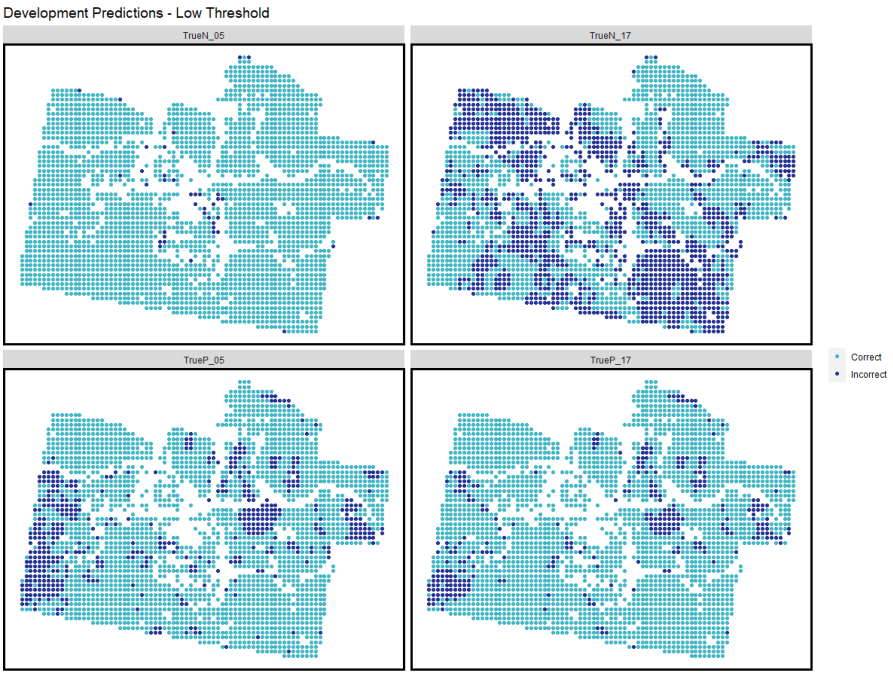
6.2. Accuracy

The threshold of 50% has a higher accuracy but also has a higher specificity. Therefore, the model with a higher specificity can better predict “no change”. The model with a higher sensitivity can better predict “new development”.

Variable	Sensitivity	Specificity	Accuracy
predClass_05	1.00	0.01	0.19
predClass_17	0.64	0.52	0.54

Given the case and the spatial distribution of land cover change, it may be more useful to have a model that predicts generally where new development occurs rather than one that predicts precisely where. As illustrated below, the 17% threshold provides this outcome.





6.3. Generalizability

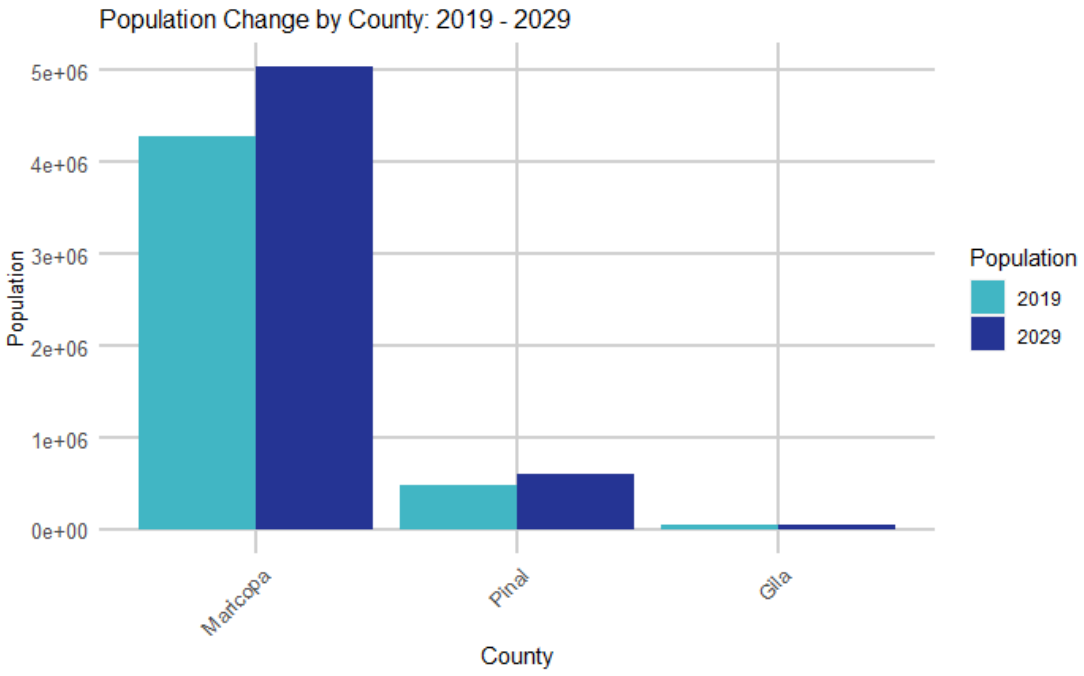
Below table shows whether the model can be applied to other geographical extent. In this section, the function called spatialCV tests the model to each county. The table shows how the model performs in counties.

county	Observed_Change	Sensitivity	Specificity	Accuracy
Gila	135	0.80	0.24	0.34
Maricopa	316	0.56	0.62	0.60
Pinal	84	0.69	0.65	0.66

7. Demand Projection

7.1. Population Change

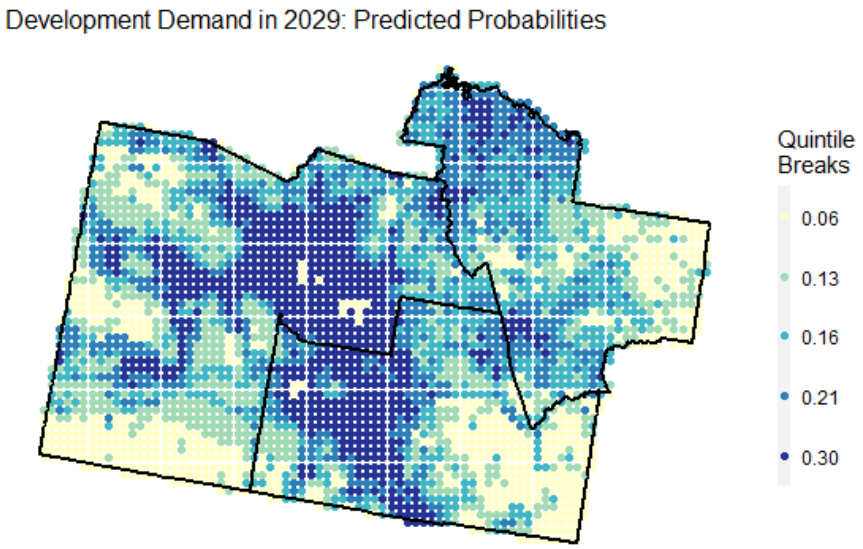
Population change data between 2009 and 2019 is an essential factor in forecasting land cover demand for 2029. Then, download the 2029 Phoenix population prediction data from https://www.azcommerce.com/oeo/population/population-projections/



7.2. Forecasting Development Demand

The map of predicted probabilities is plotted to demonstrate predicted

development demand in 2029.



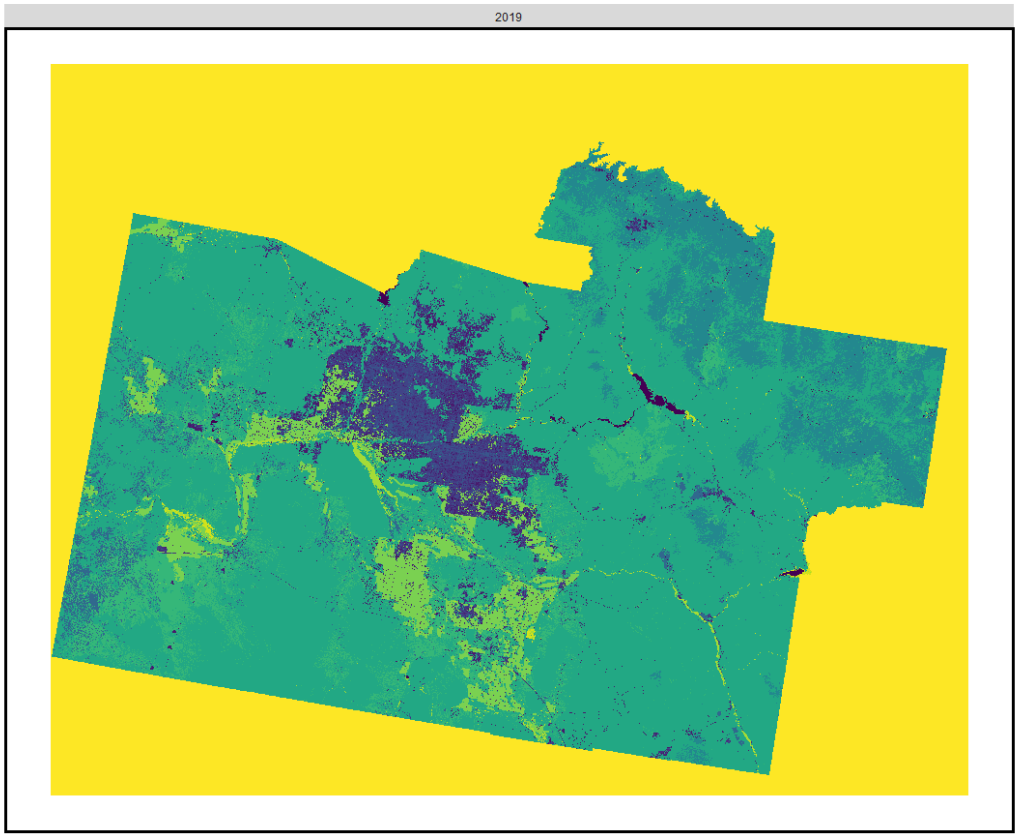
8. Evaluating Development Suitability

Through some future urban development plans released by the Phoenix Urban Planning Department in recent years, we found that in the future, the development of land resources around Phoenix should pay more attention to building a sustainable city. Therefore, besides considering the previous influencing factors, we should also pay attention to environmental sensitivity. By integrating these forecasts, planners can comprehensively consider new land suitable for future development.

8.1. Environmental Sensitivity

In this project, we assume environmentally sensitive land as wetland and forest. Environmental sensitivity is determined by measuring the total amount of wetlands and forests and the amount of lost sensitive land between 2009 and 2019.

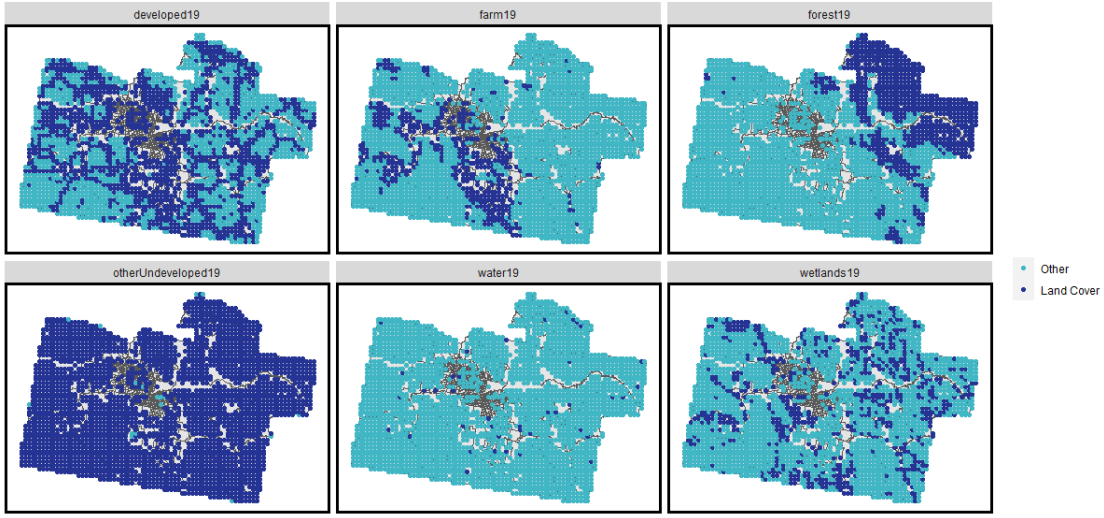
Land Cover, 2009 & 2019a



Below are the total amount of wetlands and forest land cover area in 2019.

Land Cover Types, 2019

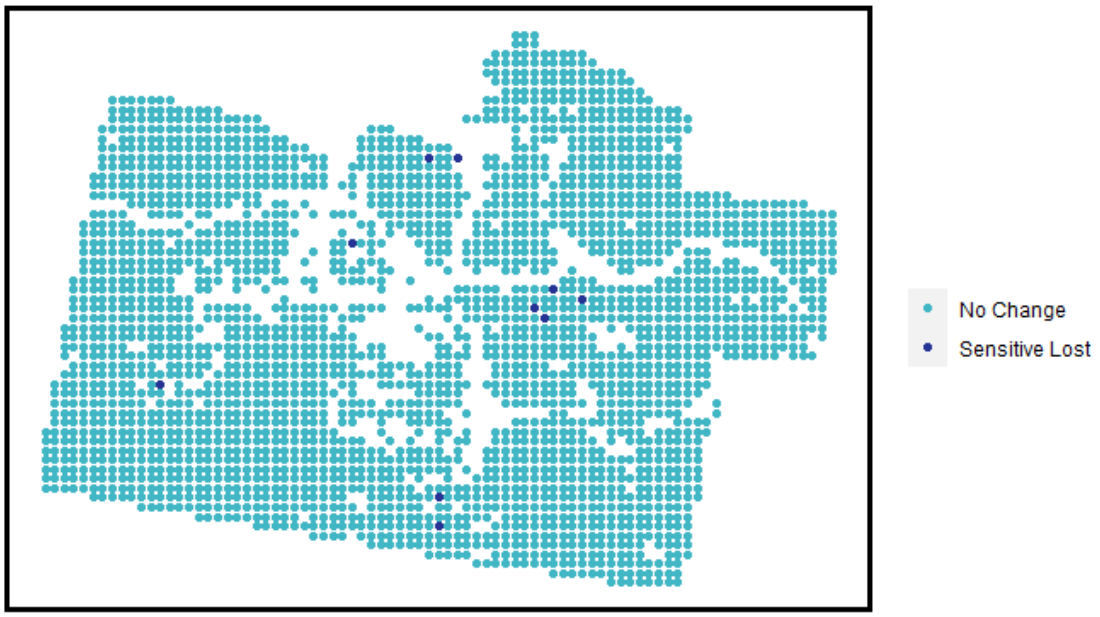
As fishnet centroids



Below is the amount of sensitive land (wetland and forest) lost between 2009 and 2019.

Sensitive lands lost: 2001 - 2011

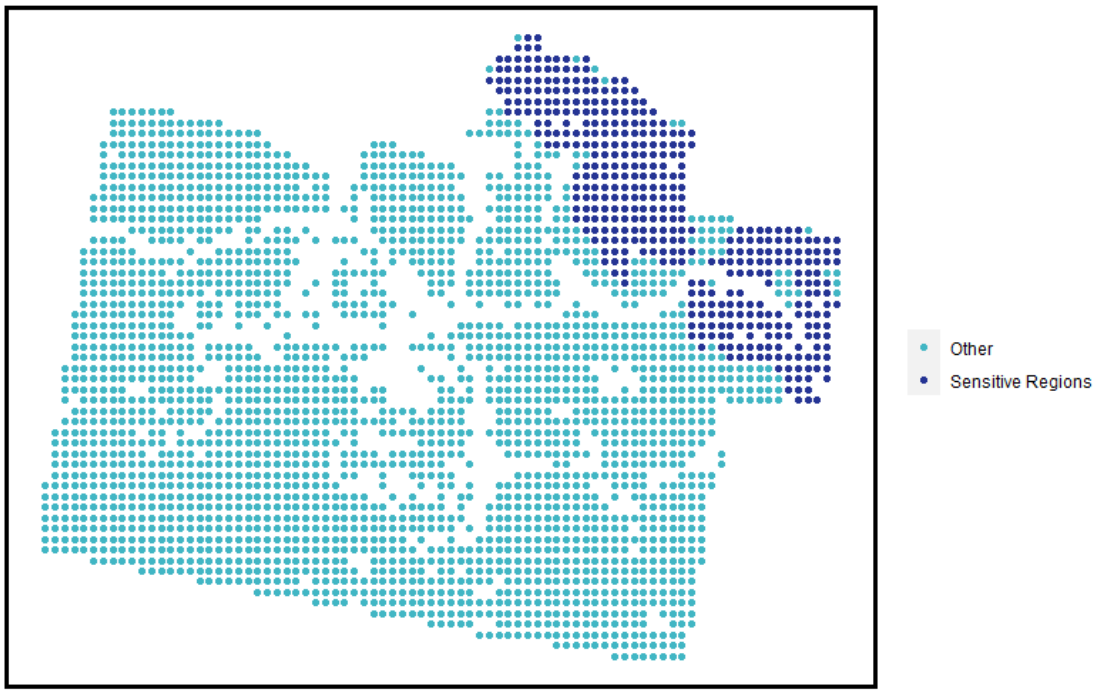
As fishnet centroids



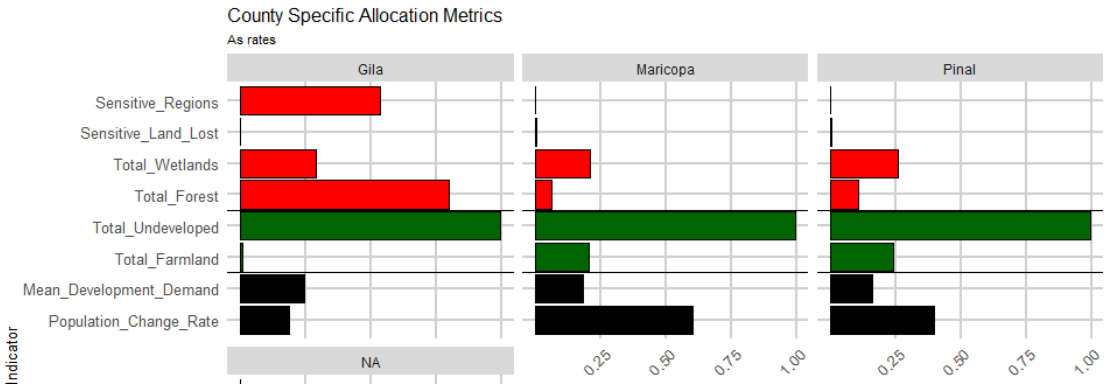
Below is the total area of large sensitive landscape which are the continuous areas of either wetlands or forests greater than 1 acre.

Sensitive regions

Continous areas of either wetlands or forests greater than 1 acre

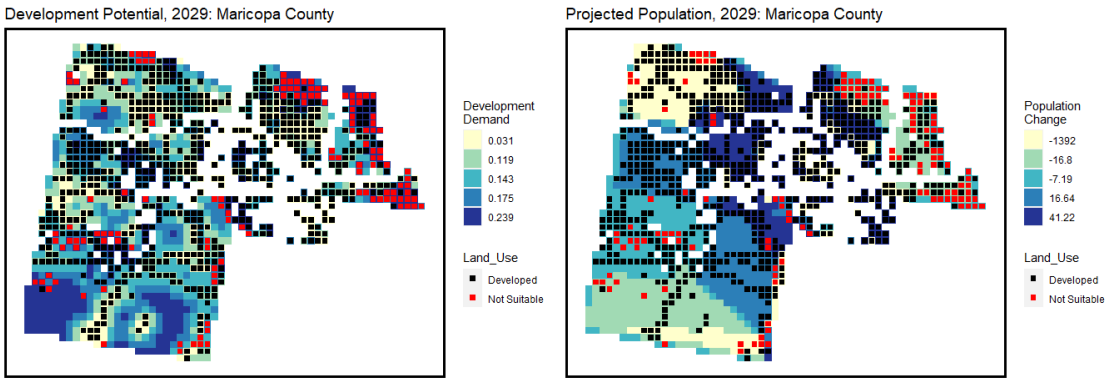


The plot below gives a sense for development demand, suitable land for development and sensitive land in a county level.



8.2. Allocation

Now this project can determine development rights of the land depending on predicted demand and environmental sensitivity. The map below shows the predicted development demand and suitable land for development of Maricopa County in Phoenix MSA.



There is a part of the land to the southeast of the metropolitan area of Maricopa that is suitable for new urban planning and urban expansion. We should plan cores, centers, and corridors to include a variety of land uses: office, retail shopping, entertainment and cultural, housing, hotel and resort, and where appropriate, some types of industry.

For the hilly area to the west of the county, which is the junction of Maricopa and Gila counties, there is a small amount of woodland and water resources critical to the city's sustainable development. For such plots, future planning should pay attention to protection.