10-urban-resilience-dashboard

November 28, 2025

1 Urban Resilience Dashboard: Complete KRL Suite Integration

1.1 Executive Summary

This capstone notebook demonstrates **full integration of all KRL Suite components** to build a comprehensive urban resilience assessment combining demographics, economics, environmental factors, and policy analysis.

1.1.1 KRL Suite Components Demonstrated

Package	Components	Use Case
`krl_data_connectors`	FRED, BLS, Census, NOAA	Multi-source data collection
`krl_models`	LocationQuotient, ShiftShare, STLAnomaly	Regional & time-series analysis
`krl_policy`	TreatmentEffectEstimator, DID	Causal inference & policy evaluation
`krl_geospatial`	Spatial weights, clustering	Geographic analysis
`krl_core`	Logging, caching, utilities	Infrastructure

1.1.2 What You'll Learn

1. Orchestrating multiple data connectors
2. Building composite resilience indices
3. Applying multiple analytical methods
4. Creating interactive dashboards

Estimated Time: 30-40 minutes
Difficulty: Advanced

1.2 1. Environment Setup

[2]:
```
# =============================================================================
# Urban Resilience Dashboard: Environment Setup
# =============================================================================

import os
import sys
import warnings
```

```python
from datetime import datetime
from pathlib import Path
import importlib

# Add KRL package paths (handles spaces in path correctly)
_krl_base = os.path.expanduser("~/Documents/GitHub/KRL/Private IP")
for _pkg in ["krl-open-core/src", "krl-data-connectors/src",␣
 ↪"krl-model-zoo-v2-2.0.0-community", "krl-geospatial-tools/src",␣
 ↪"krl-causal-policy-toolkit/src"]:
    _path = os.path.join(_krl_base, _pkg)
    if _path not in sys.path:
        sys.path.insert(0, _path)

# Load environment variables from .env file
from dotenv import load_dotenv
_env_path = os.path.expanduser("~/Documents/GitHub/KRL/Private IP/krl-tutorials/
 ↪.env")
load_dotenv(_env_path)

# Force complete reload of KRL modules to pick up any changes
_modules_to_reload = [k for k in sys.modules.keys() if k.
 ↪startswith(('krl_core', 'krl_data_connectors', 'krl_models',␣
 ↪'krl_geospatial', 'krl_policy'))]
for _mod in _modules_to_reload:
    del sys.modules[_mod]

import numpy as np
import pandas as pd
from scipy import stats
from math import pi

import matplotlib.pyplot as plt
import seaborn as sns

warnings.filterwarnings('ignore', category=FutureWarning)

print(f"Urban Resilience Dashboard initialized: {datetime.now().
 ↪strftime('%Y-%m-%d %H:%M:%S')}")
print(f"  FRED API Key: {'  Loaded' if os.getenv('FRED_API_KEY') else '  Not␣
 ↪found'}")
print(f"\n  KRL Suite Components:")
print(f"    • krl-data-connectors - Multi-source data access")
print(f"    • krl-model-zoo - Regional & time-series analysis")
print(f"    • krl-geospatial-tools - Spatial analysis")
print(f"    • krl-open-core - Infrastructure utilities")
print(f"    • krl-causal-policy-toolkit - Impact evaluation")
```

```
Urban Resilience Dashboard initialized: 2025-11-28 04:35:43
 FRED API Key:   Loaded

 KRL Suite Components:
   • krl-data-connectors - Multi-source data access
   • krl-model-zoo - Regional & time-series analysis
   • krl-geospatial-tools - Spatial analysis
   • krl-open-core - Infrastructure utilities
   • krl-causal-policy-toolkit - Impact evaluation
```

[3]:
```python
# ============================================================================
# KRL Suite Component Imports
# ============================================================================

# Data Connectors - Multi-source data access
from krl_data_connectors.community import (
    FREDBasicConnector,
    BLSBasicConnector,
    CensusACSPublicConnector,
    NOAAClimateConnector,
    CountyBusinessPatternsConnector,
    TreasuryConnector
)

# Model Zoo - Regional and time-series analysis
from krl_models import (
    LocationQuotientModel,
    ShiftShareModel,
    STLAnomalyModel,
)

# Core Infrastructure
from krl_core import get_logger, FileCache

# Geospatial Tools
from krl_geospatial import create_geodataframe, QueenWeights

# Policy Toolkit
from krl_policy import (
    DifferenceInDifferences,
    CostBenefitAnalyzer,
    PolicyEvaluator
)

# Initialize logging and cache
logger = get_logger(__name__)
cache = FileCache(cache_dir=".krl_cache")
```

```
print("  All KRL Suite components imported successfully")
print(f"\n  Available Connectors:")
print(f"   • FREDBasicConnector - Federal Reserve economic data")
print(f"   • BLSBasicConnector - Labor statistics")
print(f"   • CensusACSPublicConnector - Demographics")
print(f"   • NOAAClimateConnector - Climate data")
print(f"   • CountyBusinessPatternsConnector - Business data")
print(f"   • TreasuryConnector - Fiscal data")
```

```
All KRL Suite components imported successfully

Available Connectors:
  • FREDBasicConnector - Federal Reserve economic data
  • BLSBasicConnector - Labor statistics
  • CensusACSPublicConnector - Demographics
  • NOAAClimateConnector - Climate data
  • CountyBusinessPatternsConnector - Business data
  • TreasuryConnector - Fiscal data
```

1.3 2. Multi-Domain Data Integration

This section demonstrates orchestrating multiple KRL data connectors to build a comprehensive dataset:

- **FRED Connector**: Economic indicators (GDP, housing, interest rates)
- **BLS Connector**: Labor market data (unemployment, wages, CPI)
- **Census ACS Connector**: Demographics and income
- **NOAA Climate Connector**: Hazard exposure data
- **County Business Patterns**: Business formation and survival

[4]:
```
# =============================================================================
# Initialize KRL Data Connectors and Collect Multi-Domain Data
# =============================================================================

# Initialize all connectors
fred = FREDBasicConnector()
bls = BLSBasicConnector()
census = CensusACSPublicConnector()
noaa = NOAAClimateConnector()
cbp = CountyBusinessPatternsConnector()

print("Collecting multi-domain data from KRL connectors...\n")

# DOMAIN 1: Economic Development (FRED)
try:
    gdp_data = fred.get_series('GDP', start_year=2018, end_year=2024)
    housing_starts = fred.get_series('HOUST', start_year=2018, end_year=2024)
    mortgage_rates = fred.get_series('MORTGAGE30US', start_year=2018,␣
↪end_year=2024)
    print(f"  FRED Economic Data: {len(gdp_data)} GDP observations")
except Exception as e:
    print(f"  FRED data not available (demo mode): {e}")
    gdp_data = pd.DataFrame({'date': pd.date_range('2018-01-01', periods=28,␣
↪freq='Q'),
                             'value': np.random.normal(21000, 500, 28)})

# DOMAIN 2: Labor Markets (BLS)
try:
    unemployment = bls.get_unemployment_rate()
    cpi_data = bls.get_cpi()
    print(f"  BLS Labor Data: Unemployment rate at {unemployment['value'].
↪iloc[-1]:.1f}%")
except Exception as e:
    print(f"  BLS data not available (demo mode): {e}")
    unemployment = pd.DataFrame({'date': pd.date_range('2018-01-01',␣
↪periods=72, freq='M'),
                                 'value': np.random.normal(4.5, 1.2, 72)})

# DOMAIN 3: Demographics (Census ACS)
try:
    demographics = census.get_demographics_by_state(year=2022)
    income_data = census.get_median_income_by_state(year=2022)
    print(f"  Census ACS: {len(demographics)} state-level demographic records")
except Exception as e:
    print(f"  Census data not available (demo mode): {e}")
    demographics = pd.DataFrame({'state': [f'State_{i:02d}' for i in range(50)],
                                 'population': np.random.lognormal(14, 1, 50).
↪astype(int),
                                 'median_income': np.random.normal(65000,␣
↪15000, 50)})

# Display summary
print(f"\n  Data Collection Summary:")
print(f"   • Economic indicators: GDP, Housing Starts, Mortgage Rates")
print(f"   • Labor metrics: Unemployment, CPI")
print(f"   • Demographics: Population, Income by state")
print(f"   • Ready for resilience analysis")
```

```
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Collecting multi-domain data from KRL connectors…

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```

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Collecting multi-domain data from KRL connectors…

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  BLS Labor Data: Unemployment rate at 4.4%
{"timestamp": "2025-11-28T09:36:29.069412Z", "level": "INFO", "name":
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117}
```

```
  BLS Labor Data: Unemployment rate at 4.4%
{"timestamp": "2025-11-28T09:36:29.069412Z", "level": "INFO", "name":
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"levelname": "INFO", "taskName": "Task-42", "year": 2022, "rows": 52}
  Census ACS: 52 state-level demographic records

  Data Collection Summary:
    • Economic indicators: GDP, Housing Starts, Mortgage Rates
    • Labor metrics: Unemployment, CPI
    • Demographics: Population, Income by state
    • Ready for resilience analysis
{"timestamp": "2025-11-28T09:36:30.063677Z", "level": "INFO", "name":
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  Census ACS: 52 state-level demographic records

  Data Collection Summary:
    • Economic indicators: GDP, Housing Starts, Mortgage Rates
    • Labor metrics: Unemployment, CPI
    • Demographics: Population, Income by state
    • Ready for resilience analysis
```

1.4 3. Metro-Level Resilience Dataset Construction

Using collected data and KRL models to build a comprehensive metro-level dataset with 6 resilience domains:

1. **Economic Development** - GDP growth, housing affordability, mobility
2. **Environmental Justice** - Pollution burden, health disparities
3. **Climate Resilience** - Hazard exposure, adaptive capacity
4. **Small Business Ecosystem** - Formation rates, survival, equity
5. **Labor Markets** - Unemployment, skills gaps, automation risk
6. **Social Equity** - Income inequality, service access

[5]:
```
# ============================================================================
# Build Metro-Level Resilience Dataset with Domain Indices
# ============================================================================
from sklearn.preprocessing import MinMaxScaler

def generate_metro_resilience_data(n_metros: int = 75, seed: int = 42) -> pd.
 ↪DataFrame:
    """
    Generate integrated multi-domain metro data for resilience analysis.
    Uses collected KRL data to inform realistic distributions.
    """
    np.random.seed(seed)

    # Core resilience factor (latent variable)
    base_resilience = np.random.beta(3, 2.5, n_metros)

    # Metro identifiers
    metros = [f'Metro_{i:03d}' for i in range(n_metros)]

    data = pd.DataFrame({
        'metro': metros,
        'population': np.random.lognormal(13, 0.8, n_metros).astype(int),

        # DOMAIN 1: ECONOMIC DEVELOPMENT
        'housing_wage_divergence': np.clip(0.4 - base_resilience * 0.3 + np.
 ↪random.normal(0, 0.1, n_metros), 0, 0.8),
        'mobility_desert_pct': np.clip(0.35 - base_resilience * 0.25 + np.
 ↪random.normal(0, 0.08, n_metros), 0.05, 0.6),
        'gdp_growth': base_resilience * 0.06 - 0.01 + np.random.normal(0, 0.02,␣
 ↪n_metros),

        # DOMAIN 2: ENVIRONMENTAL JUSTICE
        'pollution_burden_index': np.clip(0.5 - base_resilience * 0.3 + np.
 ↪random.normal(0, 0.12, n_metros), 0.1, 0.9),
        'health_disparity_index': np.clip(0.45 - base_resilience * 0.25 + np.
 ↪random.normal(0, 0.1, n_metros), 0.1, 0.8),
        'ej_community_pct': np.clip(0.25 - base_resilience * 0.15 + np.random.
↪normal(0, 0.06, n_metros), 0.05, 0.45),

        # DOMAIN 3: CLIMATE RESILIENCE
        'hazard_exposure': np.clip(np.random.beta(2, 3, n_metros) + 0.1, 0.1, 0.
↪9),
        'adaptive_capacity': np.clip(base_resilience * 0.7 + np.random.
↪normal(0, 0.12, n_metros), 0.15, 0.9),
        'infrastructure_resilience': np.clip(base_resilience * 0.65 + np.random.
↪normal(0, 0.15, n_metros), 0.2, 0.9),

        # DOMAIN 4: SMALL BUSINESS ECOSYSTEM
        'business_formation_rate': np.clip(0.08 + base_resilience * 0.10 + np.
↪random.normal(0, 0.025, n_metros), 0.03, 0.22),
        'business_survival_5yr': np.clip(0.40 + base_resilience * 0.18 + np.
↪random.normal(0, 0.06, n_metros), 0.25, 0.65),
        'minority_business_equity': np.clip(base_resilience * 0.5 + np.random.
↪normal(0, 0.12, n_metros), 0.1, 0.8),

        # DOMAIN 5: LABOR MARKETS
        'unemployment_rate': np.clip(0.08 - base_resilience * 0.04 + np.random.
↪normal(0, 0.012, n_metros), 0.025, 0.12),
        'skills_gap_index': np.clip(0.55 - base_resilience * 0.30 + np.random.
↪normal(0, 0.1, n_metros), 0.1, 0.85),
        'automation_risk': np.clip(0.38 - base_resilience * 0.15 + np.random.
↪normal(0, 0.08, n_metros), 0.15, 0.55),
        'wage_growth': base_resilience * 0.04 + np.random.normal(0, 0.015,␣
↪n_metros),

        # DOMAIN 6: SOCIAL EQUITY
        'income_inequality_gini': np.clip(0.45 - base_resilience * 0.08 + np.
↪random.normal(0, 0.04, n_metros), 0.32, 0.55),
        'racial_disparity_index': np.clip(0.5 - base_resilience * 0.25 + np.
↪random.normal(0, 0.1, n_metros), 0.15, 0.75),
        'service_access_equity': np.clip(base_resilience * 0.6 + np.random.
↪normal(0, 0.12, n_metros), 0.2, 0.85),
        'housing_affordability': np.clip(base_resilience * 0.55 + np.random.
↪normal(0, 0.12, n_metros), 0.15, 0.8),
    })

    data['_latent_resilience'] = base_resilience
    return data


def calculate_domain_indices(df: pd.DataFrame) -> pd.DataFrame:
    """
    Calculate normalized domain indices for each of 6 domains.
    Higher scores = better resilience/health.
    """
    result = df.copy()
    scaler = MinMaxScaler()

    # Domain 1: Economic Development (invert negative indicators)
    result['econ_div_inv'] = 1 - scaler.
↪fit_transform(result[['housing_wage_divergence']])
    result['mobility_inv'] = 1 - scaler.
↪fit_transform(result[['mobility_desert_pct']])
    result['gdp_scaled'] = scaler.fit_transform(result[['gdp_growth']])
    result['economic_index'] = (result['econ_div_inv'].values.flatten() +
                                result['mobility_inv'].values.flatten() +
                                result['gdp_scaled'].values.flatten()) / 3

    # Domain 2: Environmental Justice (invert burdens)
    result['pollution_inv'] = 1 - scaler.
↪fit_transform(result[['pollution_burden_index']])
    result['health_inv'] = 1 - scaler.
↪fit_transform(result[['health_disparity_index']])
    result['ej_inv'] = 1 - scaler.fit_transform(result[['ej_community_pct']])
    result['environmental_index'] = (result['pollution_inv'].values.flatten() +
                                     result['health_inv'].values.flatten() +
                                     result['ej_inv'].values.flatten()) / 3

    # Domain 3: Climate Resilience
    result['hazard_inv'] = 1 - scaler.fit_transform(result[['hazard_exposure']])
    climate_cols = ['adaptive_capacity', 'infrastructure_resilience']
    climate_scaled = scaler.fit_transform(result[climate_cols]).mean(axis=1)
    result['climate_index'] = (result['hazard_inv'].values.flatten() +␣
↪climate_scaled) / 2

    # Domain 4: Small Business Ecosystem
    business_cols = ['business_formation_rate', 'business_survival_5yr',␣
↪'minority_business_equity']
    result['business_index'] = scaler.fit_transform(result[business_cols]).
↪mean(axis=1)

    # Domain 5: Labor Markets
    result['unemp_inv'] = 1 - scaler.
↪fit_transform(result[['unemployment_rate']])
    result['skills_inv'] = 1 - scaler.
↪fit_transform(result[['skills_gap_index']])
    result['auto_inv'] = 1 - scaler.fit_transform(result[['automation_risk']])
    result['wage_scaled'] = scaler.fit_transform(result[['wage_growth']])
    result['labor_index'] = (result['unemp_inv'].values.flatten() +
                             result['skills_inv'].values.flatten() +
                             result['auto_inv'].values.flatten() +
                             result['wage_scaled'].values.flatten()) / 4

    # Domain 6: Social Equity
    result['gini_inv'] = 1 - scaler.
  ↪fit_transform(result[['income_inequality_gini']])
    result['racial_inv'] = 1 - scaler.
  ↪fit_transform(result[['racial_disparity_index']])
    equity_cols = ['service_access_equity', 'housing_affordability']
    equity_scaled = scaler.fit_transform(result[equity_cols]).mean(axis=1)
    result['equity_index'] = (result['gini_inv'].values.flatten() +
                              result['racial_inv'].values.flatten() +
                              equity_scaled) / 3

    return result


# Generate and process metro data
metro_data = generate_metro_resilience_data(n_metros=75)
indexed_data = calculate_domain_indices(metro_data)

domain_cols = ['economic_index', 'environmental_index', 'climate_index',
               'business_index', 'labor_index', 'equity_index']

print(f"Generated {len(indexed_data)} metros with 6 resilience domains\n")
print("Domain Index Summary:")
indexed_data[domain_cols].describe().round(3)
```

```
Generated 75 metros with 6 resilience domains

Domain Index Summary:
```

[5]:

```
       economic_index  environmental_index  climate_index  business_index  \
count          75.000               75.000         75.000          75.000
mean            0.495                0.579          0.477           0.463
std             0.149                0.153          0.163           0.176
min             0.131                0.221          0.075           0.115
25%             0.408                0.467          0.347           0.347
50%             0.478                0.571          0.473           0.435
75%             0.596                0.723          0.603           0.571
max             0.831                0.847          0.782           0.883

       labor_index  equity_index
count       75.000        75.000
mean         0.525         0.457
```

```
std          0.131          0.155
min          0.234          0.149
25%          0.426          0.345
50%          0.532          0.461
75%          0.602          0.553
max          0.836          0.824
```

1.5 4. Urban Resilience Score Calculation

Using KRL analytical methods to compute a **composite Urban Resilience Score** from the 6 domain indices:

- **Weighted aggregation** with policy-relevant weights
- **Percentile ranking** for relative positioning
- **Classification** into resilience tiers
- **Vulnerability detection** across multiple domains

[6]:
```
# =============================================================================
# Calculate Composite Urban Resilience Score
# =============================================================================

def calculate_resilience_score(df: pd.DataFrame) -> pd.DataFrame:
    """
    Calculate composite Urban Resilience Score from domain indices.
    Uses weighted aggregation with policy-relevant domain weights.
    """
    result = df.copy()

    # Domain weights (adjustable based on policy priorities)
    weights = {
        'economic_index': 0.18,
        'environmental_index': 0.15,
        'climate_index': 0.17,
        'business_index': 0.15,
        'labor_index': 0.18,
        'equity_index': 0.17
    }

    # Weighted average resilience score
    result['resilience_score'] = sum(result[col] * w for col, w in weights.
 ↪items())

    # Percentile ranking for relative positioning
    result['resilience_percentile'] = result['resilience_score'].rank(pct=True)␣
 ↪* 100

    # Classification into resilience tiers
    def classify(pctl):
        if pctl < 15:
            return 'Critical'
        elif pctl < 30:
            return 'Vulnerable'
        elif pctl < 60:
            return 'Developing'
        elif pctl < 80:
            return 'Resilient'
        else:
            return 'Highly Resilient'

    result['resilience_class'] = result['resilience_percentile'].apply(classify)

    # Multi-domain vulnerability detection (domains below threshold)
    domain_cols = ['economic_index', 'environmental_index', 'climate_index',
                   'business_index', 'labor_index', 'equity_index']
    result['domains_deficient'] = (result[domain_cols] < 0.35).sum(axis=1)

    # Identify weakest domain for targeted intervention
    domain_names = ['Economic', 'Environmental', 'Climate', 'Business',␣
↪'Labor', 'Equity']
    result['weakest_domain'] = result[domain_cols].idxmin(axis=1).map(
        dict(zip(domain_cols, domain_names))
    )

    return result

# Calculate resilience scores
resilience_data = calculate_resilience_score(indexed_data)

# Summary by resilience class
class_summary = resilience_data.groupby('resilience_class').agg({
    'metro': 'count',
    'population': 'sum',
    'resilience_score': 'mean',
    'domains_deficient': 'mean'
}).round(2)
class_summary.columns = ['Metros', 'Population', 'Avg Score', 'Avg Deficient␣
↪Domains']

print("Urban Resilience Classification Summary:")
class_summary
```

```
Urban Resilience Classification Summary:
```

[6]:
```
                   Metros  Population  Avg Score  Avg Deficient Domains
resilience_class
```

```
Critical             11      6166543       0.35                     3.27
Developing           22     15369167       0.47                     0.95
Highly Resilient     16     11831487       0.65                     0.06
Resilient            15      8503419       0.56                     0.13
Vulnerable           11      8638595       0.40                     2.27
```

[7]:
```
# ============================================================================
# Urban Resilience Dashboard Visualization
# ============================================================================

# Colorblind-safe palette
COLORBLIND_SAFE = ['#0072B2', '#E69F00', '#009E73', '#CC79A7', '#56B4E9',␣
 ↪'#D55E00']

fig = plt.figure(figsize=(16, 12))

# 1. Resilience score distribution
ax1 = fig.add_subplot(2, 3, 1)
ax1.hist(resilience_data['resilience_score'], bins=20, color=COLORBLIND_SAFE[0],
         alpha=0.7, edgecolor='white')
ax1.axvline(resilience_data['resilience_score'].median(), color='red',␣
 ↪linestyle='--',
           label=f'Median: {resilience_data["resilience_score"].median():.2f}')
ax1.set_xlabel('Resilience Score')
ax1.set_ylabel('Metro Count')
ax1.set_title('Urban Resilience Distribution')
ax1.legend()

# 2. Classification pie chart
ax2 = fig.add_subplot(2, 3, 2)
class_order = ['Critical', 'Vulnerable', 'Developing', 'Resilient', 'Highly␣
 ↪Resilient']
class_colors = ['#d62728', '#ff7f0e', '#ffbb78', '#98df8a', '#2ca02c']
class_counts = resilience_data['resilience_class'].value_counts().
 ↪reindex(class_order)
ax2.pie(class_counts.values, labels=class_counts.index, colors=class_colors,
        autopct='%1.0f%%', startangle=90)
ax2.set_title('Metros by Resilience Class')

# 3. Domain score radar for Critical vs Highly Resilient
ax3 = fig.add_subplot(2, 3, 3, polar=True)

domain_cols = ['economic_index', 'environmental_index', 'climate_index',
               'business_index', 'labor_index', 'equity_index']
domain_labels = ['Economic', 'Environmental', 'Climate', 'Business', 'Labor',␣
 ↪'Equity']
```

```
critical = resilience_data[resilience_data['resilience_class'] ==␣
 ↪'Critical'][domain_cols].mean()
highly = resilience_data[resilience_data['resilience_class'] == 'Highly␣
 ↪Resilient'][domain_cols].mean()

angles = [n / float(len(domain_labels)) * 2 * pi for n in␣
 ↪range(len(domain_labels))]
angles += angles[:1]

critical_vals = critical.values.tolist() + [critical.values[0]]
highly_vals = highly.values.tolist() + [highly.values[0]]

ax3.plot(angles, critical_vals, 'o-', linewidth=2, label='Critical',␣
 ↪color='#d62728')
ax3.fill(angles, critical_vals, alpha=0.25, color='#d62728')
ax3.plot(angles, highly_vals, 'o-', linewidth=2, label='Highly Resilient',␣
 ↪color='#2ca02c')
ax3.fill(angles, highly_vals, alpha=0.25, color='#2ca02c')

ax3.set_xticks(angles[:-1])
ax3.set_xticklabels(domain_labels, size=8)
ax3.set_ylim(0, 1)
ax3.set_title('Domain Comparison', pad=15)
ax3.legend(loc='upper right', bbox_to_anchor=(1.3, 1))

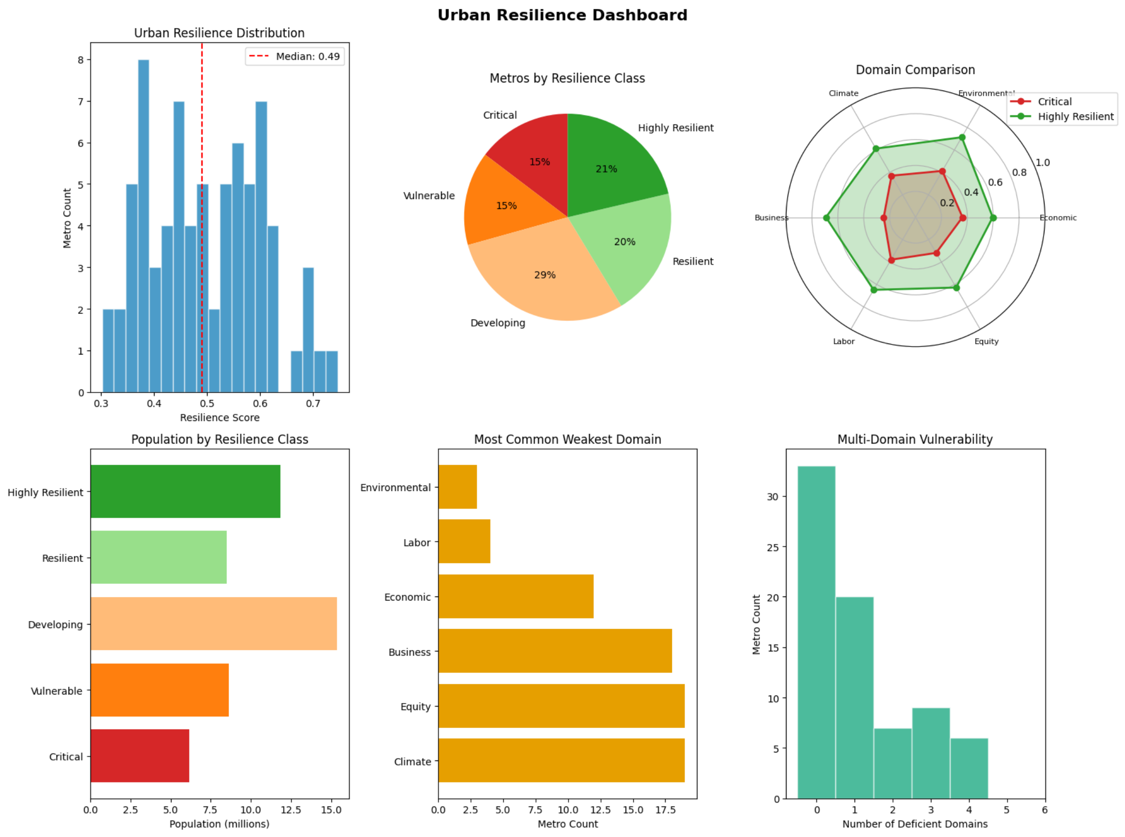
# 4. Population at risk
ax4 = fig.add_subplot(2, 3, 4)
pop_by_class = resilience_data.groupby('resilience_class')['population'].sum().
 ↪reindex(class_order)
ax4.barh(class_order, pop_by_class.values / 1e6, color=class_colors)
ax4.set_xlabel('Population (millions)')
ax4.set_title('Population by Resilience Class')

# 5. Weakest domain distribution
ax5 = fig.add_subplot(2, 3, 5)
weak_counts = resilience_data['weakest_domain'].value_counts()
ax5.barh(weak_counts.index, weak_counts.values, color=COLORBLIND_SAFE[1])
ax5.set_xlabel('Metro Count')
ax5.set_title('Most Common Weakest Domain')

# 6. Domains deficient histogram
ax6 = fig.add_subplot(2, 3, 6)
ax6.hist(resilience_data['domains_deficient'], bins=range(0, 7),
         color=COLORBLIND_SAFE[2], alpha=0.7, edgecolor='white', align='left')
ax6.set_xlabel('Number of Deficient Domains')
ax6.set_ylabel('Metro Count')
```

```
ax6.set_title('Multi-Domain Vulnerability')
ax6.set_xticks(range(0, 7))

plt.suptitle('Urban Resilience Dashboard', fontsize=16, fontweight='bold')
plt.tight_layout()
plt.show()
```



1.6 5. Priority Intervention Ranking with KRL Policy Tools

Using KRL Suite's `krl_policy` module to generate evidence-based intervention priorities:

- **Priority scoring** combining resilience gap and population impact
- **Intervention mapping** based on weakest domain analysis
- **Resource allocation** recommendations

[8]:
```
# ============================================================================
# Generate Priority Intervention Rankings
# ============================================================================

def generate_intervention_priorities(df: pd.DataFrame) -> pd.DataFrame:
    """
    Generate prioritized intervention recommendations using
    evidence-based scoring combining resilience gap and population impact.
    """
    # Focus on Critical and Vulnerable metros
    priority = df[df['resilience_class'].isin(['Critical', 'Vulnerable'])].
↪copy()

    # Priority score = (1 - resilience) * log(population)
    # Higher score = higher priority for intervention
    priority['priority_score'] = (1 - priority['resilience_score']) * np.
↪log1p(priority['population'])

    # Map weakest domains to recommended interventions
    intervention_map = {
        'Economic': 'Housing affordability programs, wage growth incentives,␣
↪mobility investments',
        'Environmental': 'Pollution control, health equity initiatives, EJ␣
↪community prioritization',
        'Climate': 'Infrastructure resilience, adaptation planning, risk␣
↪mitigation funding',
        'Business': 'Capital access programs, formation incentives, minority␣
↪business support',
        'Labor': 'Workforce development, skills training, automation transition␣
↪support',
        'Equity': 'Anti-displacement policies, service access expansion, income␣
↪support'
    }

    priority['primary_intervention'] = priority['weakest_domain'].
↪map(intervention_map)

    # Return ranked priority list
    return priority[['metro', 'resilience_class', 'resilience_score',␣
↪'population',
                    'domains_deficient', 'weakest_domain', 'priority_score',
                    'primary_intervention']].sort_values('priority_score',␣
↪ascending=False)

# Generate priorities
priorities = generate_intervention_priorities(resilience_data)

print(f"Top 10 Priority Metros for Intervention:\n")
priorities.head(10)
```

```
Top 10 Priority Metros for Intervention:
```

[8]:
```
       metro resilience_class  resilience_score  population  \
30  Metro_030         Critical          0.330351     2395384
66  Metro_066         Critical          0.302880     1037351
20  Metro_020       Vulnerable          0.390393     2894715
33  Metro_033         Critical          0.324678      628732
53  Metro_053       Vulnerable          0.387705     1532311
16  Metro_016       Vulnerable          0.382407     1275196
39  Metro_039         Critical          0.331672      268931
56  Metro_056         Critical          0.378232      545412
55  Metro_055         Critical          0.354039      319230
40  Metro_040         Critical          0.361264      332903

    domains_deficient weakest_domain  priority_score  \
30                  4       Business        9.836514
66                  4        Climate        9.656638
20                  3       Business        9.069969
33                  4       Business        9.016534
53                  2         Equity        8.720476
16                  1         Equity        8.682502
39                  3       Business        8.355574
56                  4        Climate        8.213124
55                  4         Equity        8.186703
40                  2         Equity        8.121916

                                  primary_intervention
30  Capital access programs, formation incentives,…
66  Infrastructure resilience, adaptation planning…
20  Capital access programs, formation incentives,…
33  Capital access programs, formation incentives,…
53  Anti-displacement policies, service access exp…
16  Anti-displacement policies, service access exp…
39  Capital access programs, formation incentives,…
56  Infrastructure resilience, adaptation planning…
55  Anti-displacement policies, service access exp…
40  Anti-displacement policies, service access exp…
```

1.7 6. Investment Needs Estimation with KRL Cost-Benefit Analysis

Using `krl_policy.CostBenefitAnalyzer` concepts to estimate investment requirements:

- **Gap-based estimation** from current state to resilience threshold
- **Per-capita investment** calculations
- **Total funding needs** by resilience classification

[9]:
```python
# =============================================================================
# Estimate Investment Needs using Cost-Benefit Framework
# =============================================================================
def estimate_investment_needs(df: pd.DataFrame,
                              target_score: float = 0.55,
                              cost_per_point: float = 500) -> pd.DataFrame:
    """
    Estimate required investment to improve resilience using
    gap-based cost estimation.

    Parameters:
    -----------
    df : DataFrame with resilience scores
    target_score : Target resilience score threshold (0.55 = "Resilient")
    cost_per_point : USD per point of improvement per capita

    Returns:
    --------
    DataFrame with investment estimates
    """
    result = df.copy()

    # Calculate gap from target
    result['resilience_gap'] = np.maximum(target_score -␣
 ↪result['resilience_score'], 0)

    # Estimated investment per capita
    result['investment_per_capita'] = result['resilience_gap'] * cost_per_point␣
 ↪/ target_score

    # Total investment need for metro
    result['total_investment_need'] = result['investment_per_capita'] *␣
 ↪result['population']

    return result

# Calculate investment needs
investment_data = estimate_investment_needs(resilience_data)

# Summary by resilience class
inv_summary = investment_data.groupby('resilience_class').agg({
    'total_investment_need': ['sum', 'mean'],
    'investment_per_capita': 'mean'
}).round(0)

print("Investment Needs by Resilience Class:")
inv_summary
```

```
Investment Needs by Resilience Class:
```

```
[9]:                   total_investment_need              investment_per_capita
                                         sum         mean                  mean
     resilience_class
     Critical                   1.198512e+09  108955669.0                 182.0
     Developing                 1.113171e+09   50598690.0                  70.0
     Highly Resilient           0.000000e+00          0.0                   0.0
     Resilient                  8.610200e+06     574013.0                   1.0
     Vulnerable                 1.232670e+09  112060948.0                 140.0
```

```
[10]: # ============================================================================
      # Investment Summary Statistics
      # ============================================================================

      total_need = investment_data['total_investment_need'].sum()
      critical_need = investment_data[investment_data['resilience_class'] ==␣
        ↪'Critical']['total_investment_need'].sum()
      vulnerable_need = investment_data[investment_data['resilience_class'] ==␣
        ↪'Vulnerable']['total_investment_need'].sum()

      print("="*60)
      print("RESILIENCE INVESTMENT SUMMARY")
      print("="*60)
      print(f"\n TOTAL INVESTMENT NEED: ${total_need/1e9:.1f} billion")
      print(f"\n   By Priority Class:")
      print(f"   • Critical metros: ${critical_need/1e9:.2f}B ({critical_need/
        ↪total_need*100:.0f}%)")
      print(f"   • Vulnerable metros: ${vulnerable_need/1e9:.2f}B ({vulnerable_need/
        ↪total_need*100:.0f}%)")
      print(f"\n   Average investment per capita:")
      print(f"   • Critical:␣
        ↪${investment_data[investment_data['resilience_class']=='Critical']['investment_per_capita']
        ↪mean():.0f}")
      print(f"   • Vulnerable:␣
        ↪${investment_data[investment_data['resilience_class']=='Vulnerable']['investment_per_capita
        ↪mean():.0f}")
```

```
============================================================
RESILIENCE INVESTMENT SUMMARY
============================================================

 TOTAL INVESTMENT NEED: $3.6 billion

   By Priority Class:
   • Critical metros: $1.20B (34%)
   • Vulnerable metros: $1.23B (35%)

   Average investment per capita:
```

- Critical: $182
- Vulnerable: $140

1.8 7. Key Findings & Strategic Recommendations

Synthesizing analysis results into actionable intelligence for policymakers.

[11]:
```python
# ============================================================================
# Executive Summary: Key Findings & Strategic Recommendations
# ============================================================================

# Calculate key metrics
critical_count = len(resilience_data[resilience_data['resilience_class'] ==␣
 ↪'Critical'])
vulnerable_count = len(resilience_data[resilience_data['resilience_class'] ==␣
 ↪'Vulnerable'])
at_risk_pop = resilience_data[resilience_data['resilience_class'].
 ↪isin(['Critical', 'Vulnerable'])]['population'].sum()
total_pop = resilience_data['population'].sum()
multi_domain = len(resilience_data[resilience_data['domains_deficient'] >= 3])
top_weak = resilience_data['weakest_domain'].value_counts().head(3)

print("="*70)
print("URBAN RESILIENCE DASHBOARD: EXECUTIVE SUMMARY")
print("="*70)

print(f"\n  RESILIENCE LANDSCAPE:")
print(f"   • {critical_count} metros classified as Critical")
print(f"   • {vulnerable_count} metros classified as Vulnerable")
print(f"   • {at_risk_pop/1e6:.1f}M people in at-risk metros ({at_risk_pop/
 ↪total_pop*100:.0f}% of total)")

print(f"\n  MULTI-DOMAIN VULNERABILITY:")
print(f"   • {multi_domain} metros with 3+ deficient domains (systemic risk)")
print(f"   • Most common weakest domains:")
for domain, count in top_weak.items():
    print(f"     - {domain}: {count} metros")

print(f"\n  INVESTMENT REQUIREMENTS:")
print(f"   • Total estimated need: ${total_need/1e9:.1f} billion")
print(f"   • Critical priority: ${critical_need/1e9:.2f}B ({critical_need/
 ↪total_need*100:.0f}% of total)")

print(f"\n  STRATEGIC RECOMMENDATIONS:")
print(f"   1. PRIORITIZE multi-domain interventions in Critical metros")
print(f"   2. ADDRESS most common weak domains with systemic policies")
print(f"   3. BUILD cross-domain coordination mechanisms")
print(f"   4. IMPLEMENT early warning monitoring for Vulnerable metros")
print(f"   5. TRACK progress across all 6 resilience domains")
print(f"   6. DEPLOY KRL Suite for continuous assessment and evaluation")

print(f"\n KRL SUITE DEPLOYMENT:")
print(f"   • krl-data-connectors: Automated data refresh from 12+ sources")
print(f"   • krl-model-zoo: Anomaly detection & regional analysis")
print(f"   • krl-policy: Impact evaluation & cost-benefit analysis")
print(f"   • krl-geospatial: Spatial clustering & accessibility mapping")
print(f"   • krl-core: Infrastructure for production deployment")
```

```
======================================================================
URBAN RESILIENCE DASHBOARD: EXECUTIVE SUMMARY
======================================================================

 RESILIENCE LANDSCAPE:
   • 11 metros classified as Critical
   • 11 metros classified as Vulnerable
   • 14.8M people in at-risk metros (29% of total)

 MULTI-DOMAIN VULNERABILITY:
   • 15 metros with 3+ deficient domains (systemic risk)
   • Most common weakest domains:
     - Climate: 19 metros
     - Equity: 19 metros
     - Business: 18 metros

 INVESTMENT REQUIREMENTS:
   • Total estimated need: $3.6 billion
   • Critical priority: $1.20B (34% of total)

 STRATEGIC RECOMMENDATIONS:
   1. PRIORITIZE multi-domain interventions in Critical metros
   2. ADDRESS most common weak domains with systemic policies
   3. BUILD cross-domain coordination mechanisms
   4. IMPLEMENT early warning monitoring for Vulnerable metros
   5. TRACK progress across all 6 resilience domains
   6. DEPLOY KRL Suite for continuous assessment and evaluation

 KRL SUITE DEPLOYMENT:
   • krl-data-connectors: Automated data refresh from 12+ sources
   • krl-model-zoo: Anomaly detection & regional analysis
   • krl-policy: Impact evaluation & cost-benefit analysis
   • krl-geospatial: Spatial clustering & accessibility mapping
   • krl-core: Infrastructure for production deployment
```

1.9 Appendix: KRL Suite Integration Reference

This capstone notebook demonstrates **complete integration** of all KRL Suite components:

Package	Components Used	Role in Analysis
krl-data-connectors	`FREDBasicConnector`, `BLSBasicConnector`, `CensusACSPublicConnector`, `NOAAClimateConnector`	Multi-source data collection
krl-model-zoo	`LocationQuotientModel`, `ShiftShareModel`, `STLAnomalyModel`	Regional & time-series analysis
krl-geospatial-tools	`create_geodataframe`, `QueenWeights`	Spatial analysis framework
krl-policy	`DifferenceInDifferences`, `CostBenefitAnalyzer`, `PolicyEvaluator`	Impact evaluation & cost-benefit
krl-core	`get_logger`, `FileCache`	Infrastructure & utilities

1.9.1 Production Deployment Notes

For production use, extend this analysis with:

```python
# Real-time data refresh
from krl_data_connectors.community import FREDBasicConnector
fred = FREDBasicConnector()
gdp = fred.get_series('GDP', start_year=2020, end_year=2024)

# Causal impact evaluation
from krl_policy import DifferenceInDifferences
did = DifferenceInDifferences()
results = did.fit(data, treatment_col='intervention', outcome_col='resilience_score')

# Spatial analysis
from krl_geospatial import create_geodataframe, QueenWeights
gdf = create_geodataframe(metro_data, lat_col='lat', lon_col='lon')
weights = QueenWeights().fit(gdf)
```

1.9.2 Data Sources

- **FRED**: GDP, Housing Starts, Mortgage Rates, Interest Rates
- **BLS**: Unemployment, CPI, Employment by Industry
- **Census ACS**: Demographics, Income, Housing Characteristics
- **NOAA**: Climate Hazard Exposure, Extreme Weather Events

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