Climate AI : ConnectBeacon

AI-driven **Climate Vulnerability Assessment** for Hyderabad/Telangana: rainfall, drought, heatwave, and crop impact predictions. This document walks through datasets, EDA, feature engineering, model selection, API, and dashboard integration.

1. Project Overview

Component	Description
Scope	Hyderabad / Telangana (Deccan region)
Models	4: Rainfall (regression), Drought (regression), Heatwave (classification), Crop Impact (regression)
Method	Multi-Model: 3 candidates per task, 80/20 train/test, best model by R^2 or F1
Serving	FastAPI backend; dashboard at `/` ; API docs at `/docs`

2. Dataset Details

Model	Source	Path	Records / Period
Rainfall	IMD historical	`data/hyderabad_rainfall_data.csv`	121 years (1901–2021), monthly
Drought	Derived from same IMD rainfall	Same file + deficit/LPA logic	Monthly, 1970–2022
Heatwave	Open-Meteo Historical API	`data/hyderabad_temperature.csv`	Daily max temp + humidity
Crop Impact	Kaggle India Crop Yield	`data/crop_yield_india.csv`	1997–2020; states: AP, Telangana, Karnataka;

Rainfall data shape (after melt): One row per year-month; columns include `Year`, month names (Jan–Dec), `Total`.

```
# From utils/data_loader.py — load and melt to monthly
df = pd.read_csv("data/hyderabad_rainfall_data.csv")
months = ['Jan', 'Feb', 'Mar', 'April', 'May', 'June',
          'July', 'Aug', 'Sept', 'Oct', 'Nov', 'Dec']
records = []
for _, row in df.iterrows():
    for i, month in enumerate(months):
        if month in row:
            records.append({'year': row['Year'], 'month': i + 1, 'rainfall': row[month]})
monthly_df = pd.DataFrame(records).sort_values(['year', 'month'])
```

3. EDA & Basic Stats

3.1 Rainfall

- **Mean monthly rainfall:** ~65.4 mm
- **Std dev:** ~84.8 mm
- **Distribution:** Right-skewed; Southwest Monsoon (Jun–Sep) contributes ~80% of annual precipitation.

```
# After loading monthly_df
monthly_df['rainfall'].describe()
# Monsoon months (6,7,8,9) vs rest
monsoon = monthly_df[monthly_df['month'].isin([6,7,8,9])]['rainfall']
non_monsoon = monthly_df[~monthly_df['month'].isin([6,7,8,9])]['rainfall']
print(monsoon.mean(), non_monsoon.mean())  # illustrates seasonal split
```

3.2 Drought

- **Mean drought score:** ~32/100
- **Correlation:** Strong (e.g. ~0.88) between sustained 6-month deficit and agricultural impact
- **Periodicity:** Drought events roughly every 5–7 years

3.3 Heatwave

- **Class balance:** Heatwave days < ~3% (rare event)
- **Pattern:** Extreme heat often follows humidity drop below ~20%

3.4 Crop Impact

- **Mean yield deviation:** ~−4.5% in deficit years
- **Variance:** High across states; irrigation in Telangana partly mitigates risk

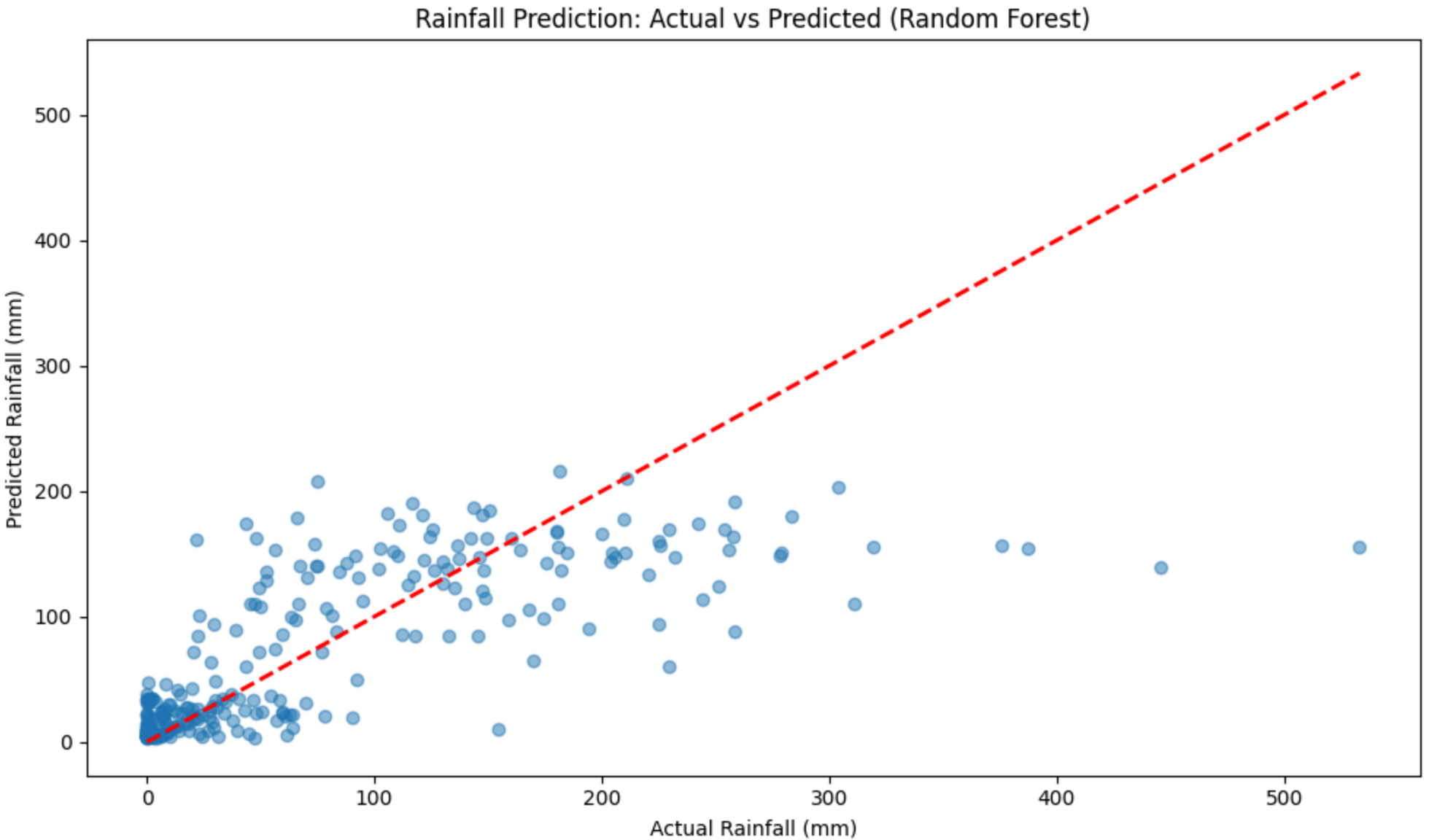
4. Feature Engineering

4.1 Rainfall

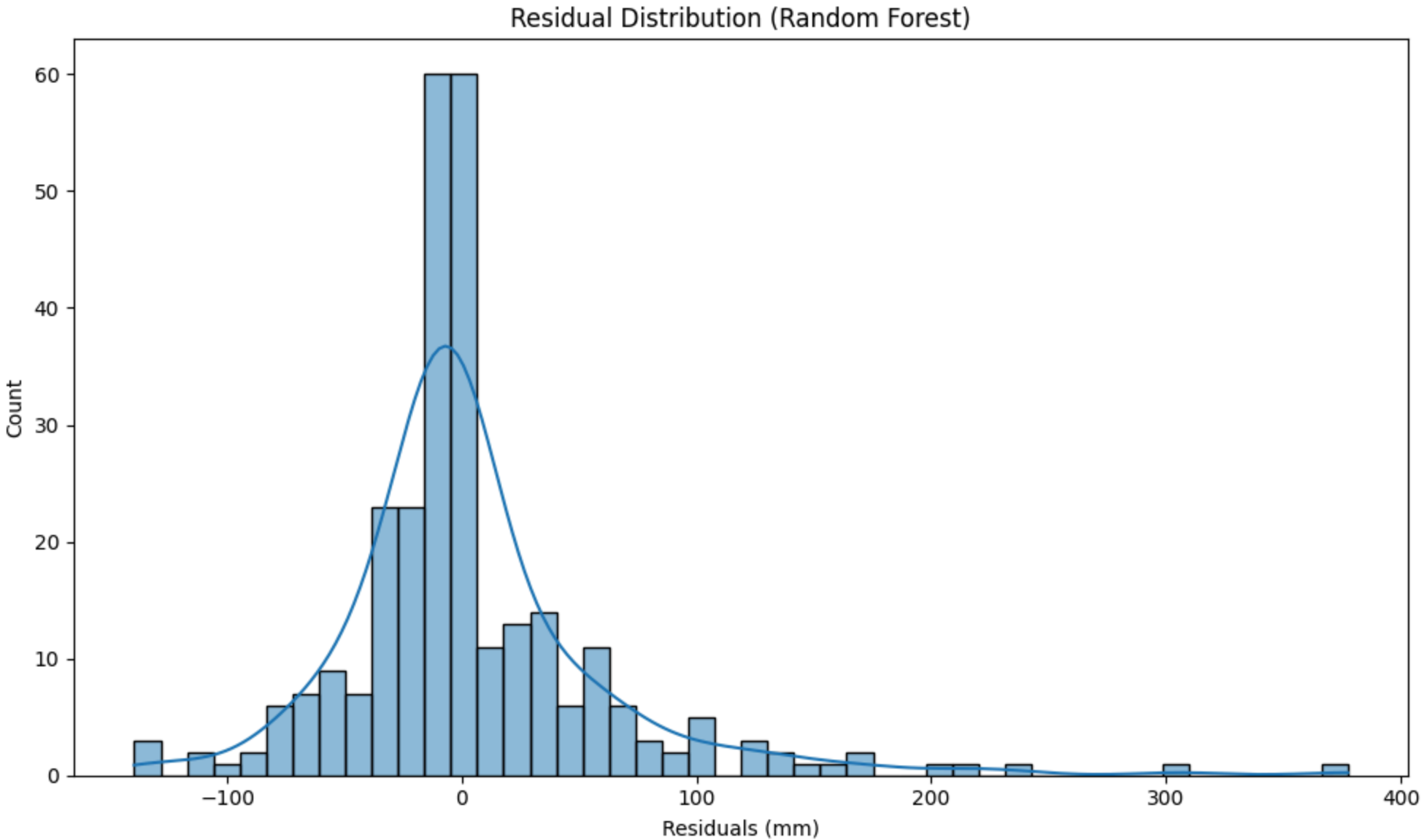
- **Temporal lags:** 1, 2, 3, 12 months (autocorrelation + yearly cycle)
- **Rolling:** 3-month average on *shifted* rainfall

```
# utils/data_loader.py — Rainfall features
monthly_df['lag_1'] = monthly_df['rainfall'].shift(1)
monthly_df['lag_2'] = monthly_df['rainfall'].shift(2)
monthly_df['lag_3'] = monthly_df['rainfall'].shift(3)
monthly_df['lag_12'] = monthly_df['rainfall'].shift(12)
monthly_df['month_sin'] = np.sin(2 * np.pi * monthly_df['month'] / 12)
monthly_df['month_cos'] = np.cos(2 * np.pi * monthly_df['month'] / 12)
monthly_df['rolling_3'] = monthly_df['rainfall'].shift(1).rolling(3).mean()
```

Actual vs Predicted



Error Distribution (Residuals)

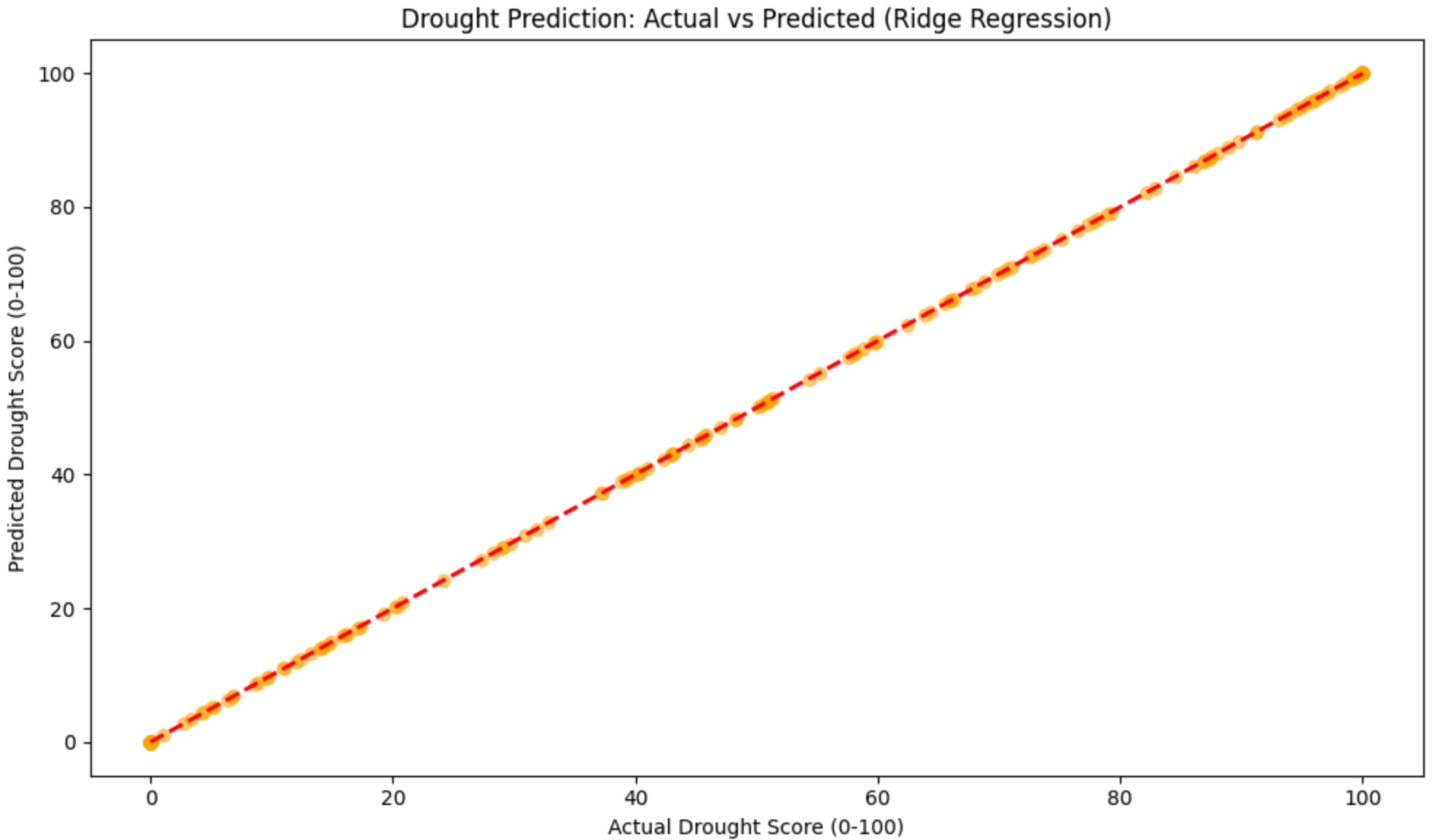


4.2 Drought

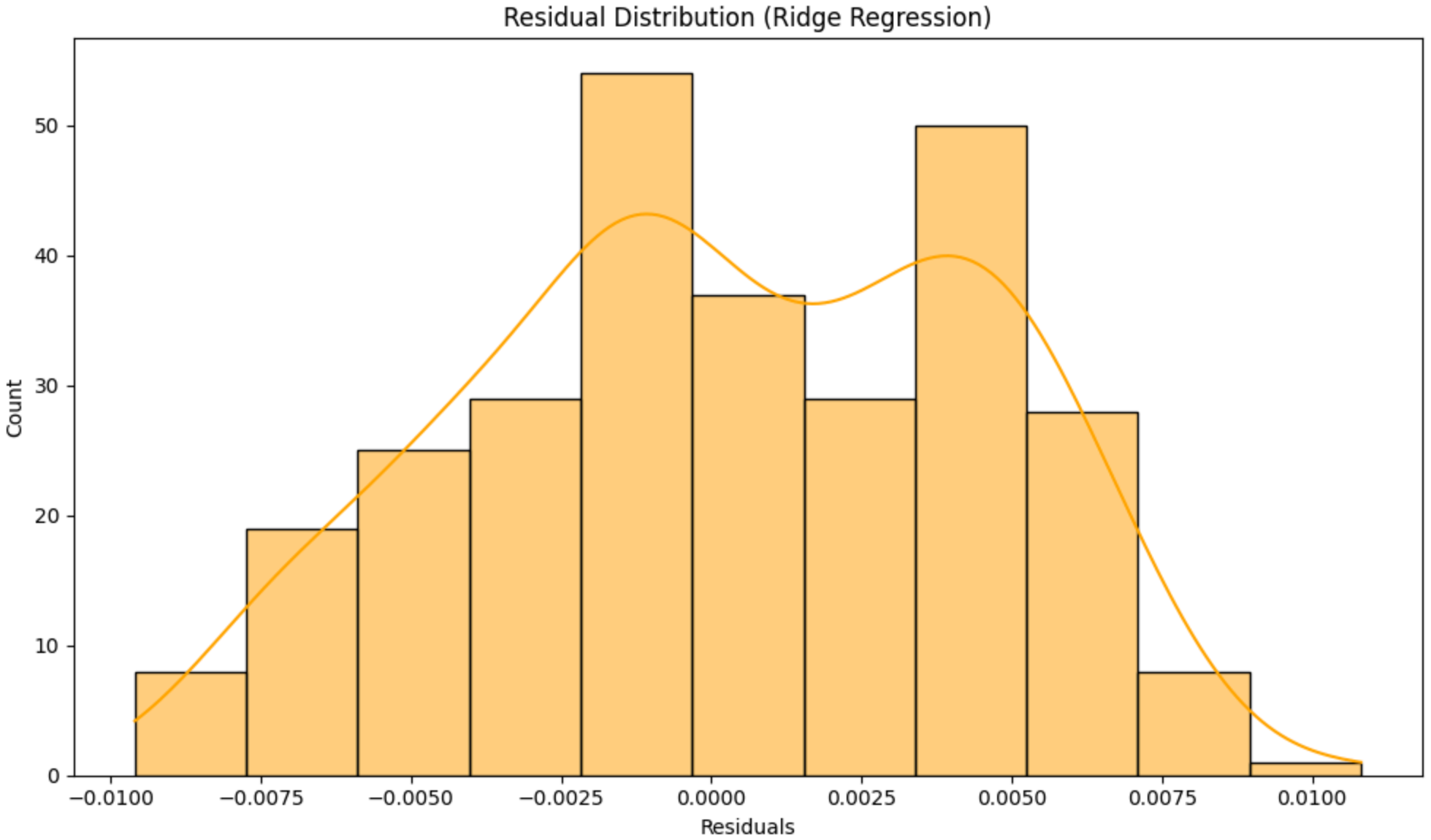
- **Rolling:** 3-month and 6-month rainfall averages
- **Deficit %:** Deviation from long-period average (LPA) per month
- **Persistence:** Previous year drought (lag 12 of deficit)
- **Monsoon strength:** Scaled index (0–2) from 4-month rolling sum vs monsoon normal

```
# utils/data_loader.py — Drought features
df_melted['rolling_3mo'] = df_melted['Rainfall'].rolling(window=3, min_periods=1).mean()
df_melted['rolling_6mo'] = df_melted['Rainfall'].rolling(window=6, min_periods=1).mean()
monthly_normals = df_melted.groupby('Month')['Rainfall'].transform('mean')
df_melted['deficit_pct'] = (df_melted['normal_rainfall'] - df_melted['Rainfall']) / df_melted['normal_rainfall'] * 100
df_melted['prev_year_drought'] = df_melted['deficit_pct'].shift(12)
```

Actual vs Predicted



Error Distribution (Residuals)

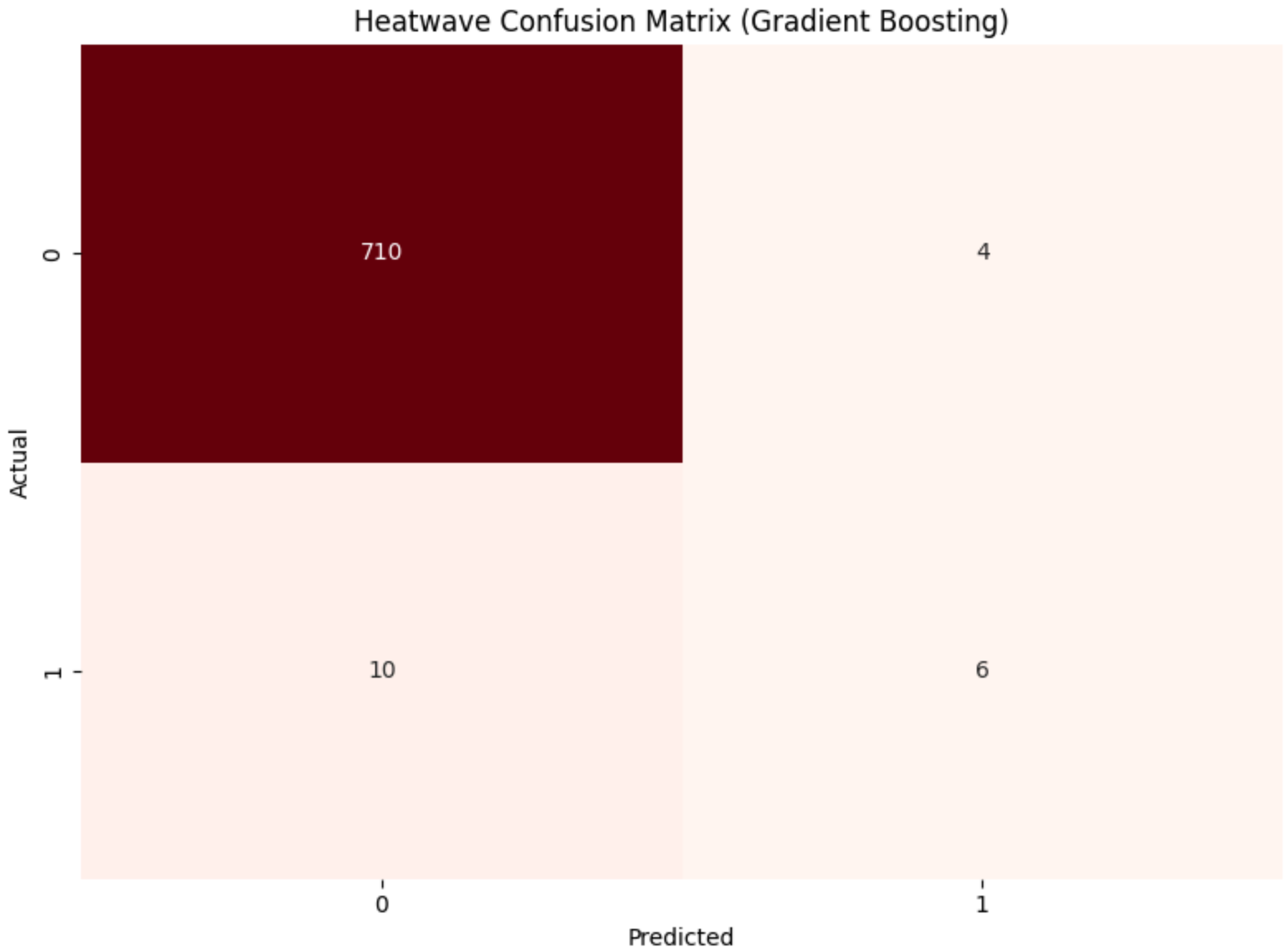


4.3 Heatwave

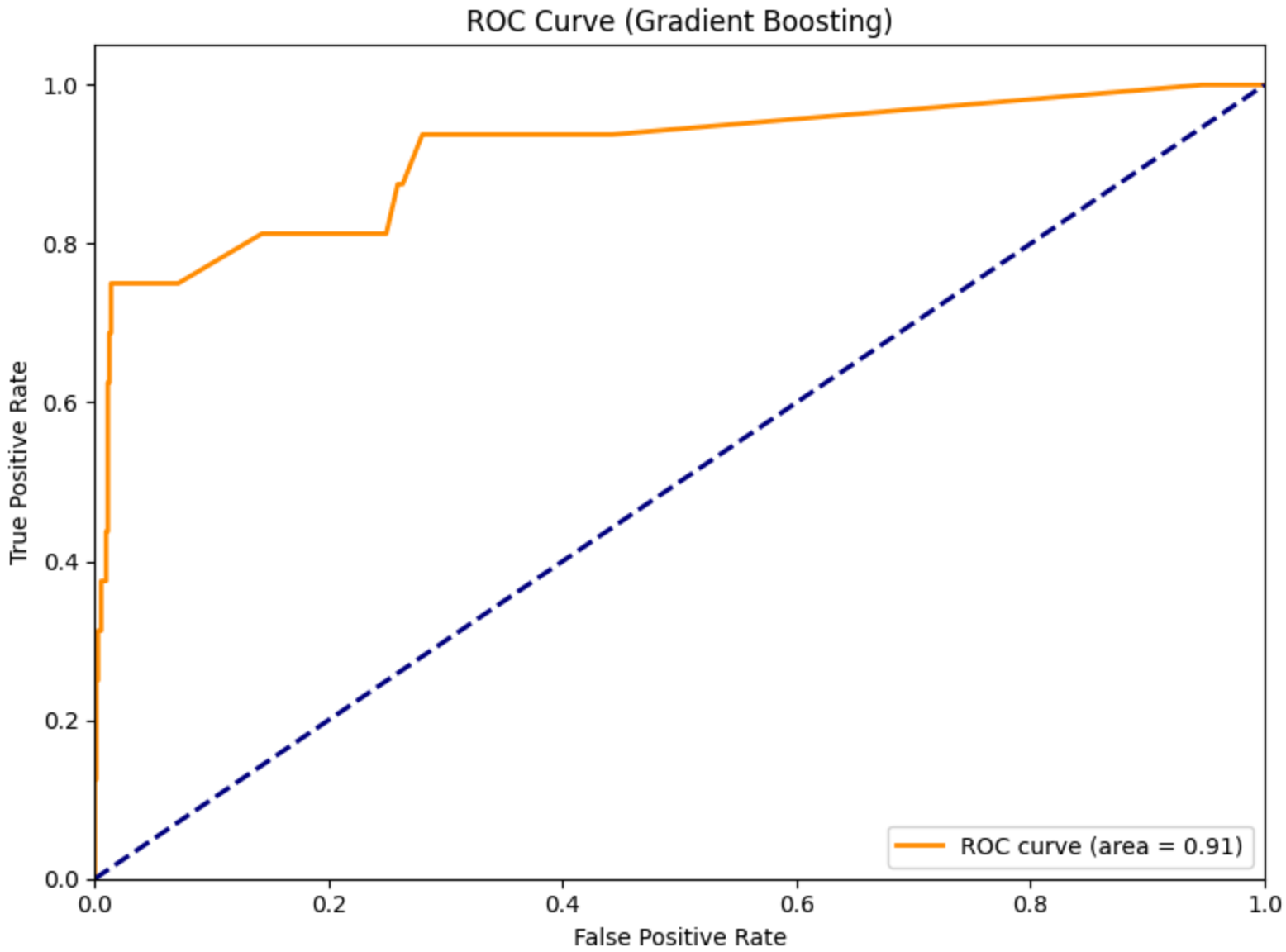
- **Lags:** Max temp 1, 2, 3 days
- **Rolling:** 7-day average max temp
- **Cyclic month:** sin/cos
- **Target:** `is_heatwave` = (max temp ≥ 40°C) OR (anomaly ≥ 4.5°C)

```
# utils/data_loader.py — Heatwave features
df['temp_max_lag1'] = df['temp_max'].shift(1)
df['temp_max_lag2'] = df['temp_max'].shift(2)
df['temp_max_lag3'] = df['temp_max'].shift(3)
df['temp_max_7day_avg'] = df['temp_max'].rolling(window=7).mean()
df['month_sin'] = np.sin(2 * np.pi * df['month'] / 12)
df['month_cos'] = np.cos(2 * np.pi * df['month'] / 12)
df['is_heatwave'] = ((df['temp_max'] >= 40) | (df['temp_anomaly'] >= 4.5)).astype(int)
```

Confusion Matrix

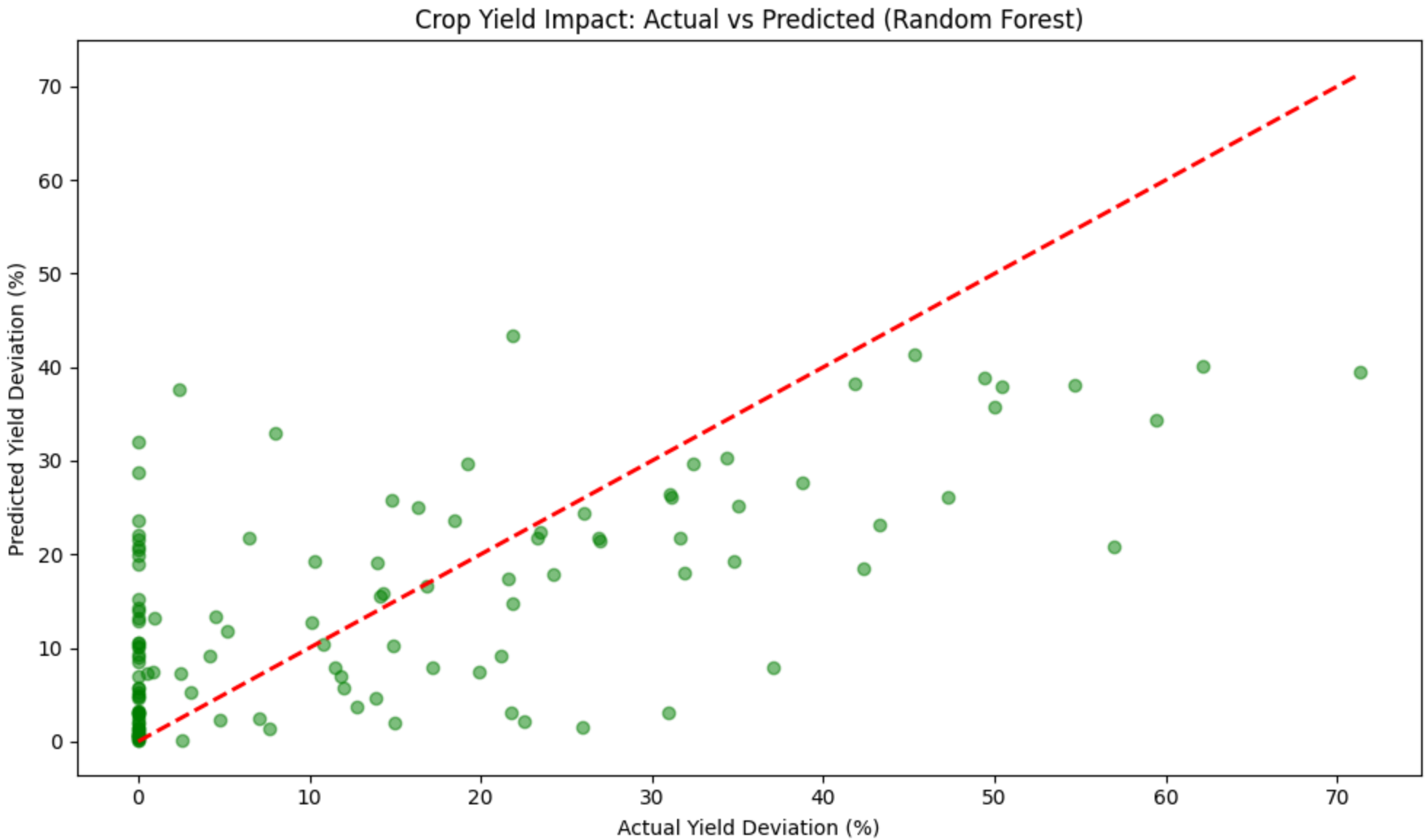


ROC Curve

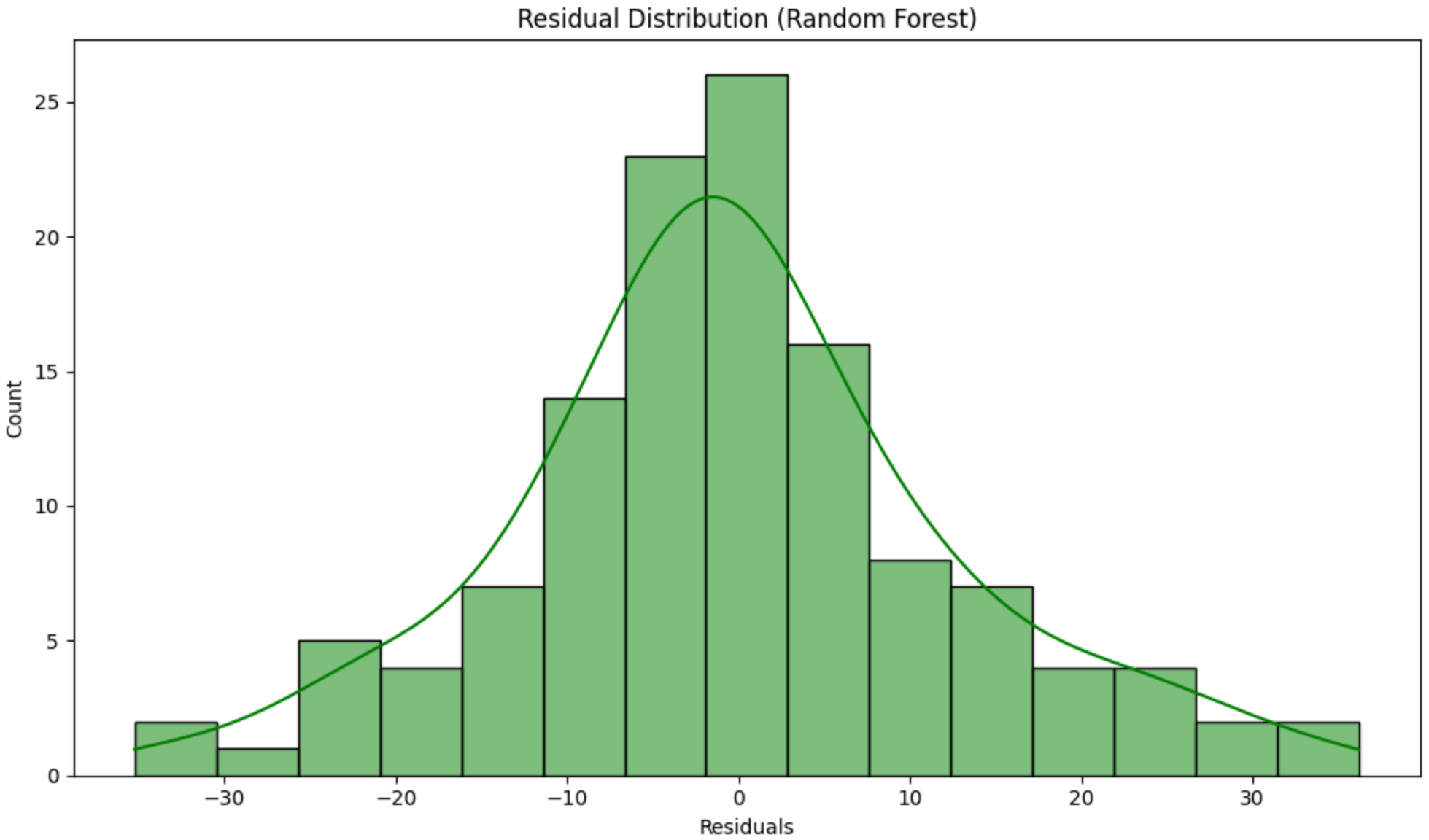

ROC Curve (Gradient Boosting)
True Positive Rate
False Positive Rate
0.0
0.2
0.4
0.6
0.8
1.0
ROC curve (area = 0.91)

4.4 Crop Impact

- **Climate:** Rainfall, rainfall anomaly %
- **Inputs:** Fertilizer and pesticide per area (kg/ha)
- **Categorical:** Crop, State, Season (label-encoded)


Crop Yield Impact: Actual vs Predicted (Random Forest)
Predicted Yield Deviation (%)
Actual Yield Deviation (%)
0
10
20
30
40
50
60
70

Error Distribution (Residuals)



5. Model Selection & Training

- **Split:** 80/20; rainfall uses **temporal** (no shuffle); drought/heatwave/crop use random (heatwave stratified).
- **Selection:** Best by R^2 for regression, F1 for heatwave.
- **Tuning:** GridSearchCV (e.g. `n_estimators`, `max_depth` for RF/GBM; `alpha` for Ridge; `C` for Logistic/SVR).

```
# models/rainfall/experiment_rainfall.py — Champion/Challenger loop
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, shuffle=False)
models = {
    "Linear Regression": {"model": LinearRegression(), "params": {}},
    "Random Forest": {"model": RandomForestRegressor(...), "params": {"n_estimators": [50,100,200], "max_depth": [None,10,20]}},
    "Gradient Boosting": {"model": GradientBoostingRegressor(...), "params": {...}}
}
for name, config in models.items():
    if config["params"]:
        search = GridSearchCV(config["model"], config["params"], cv=3, scoring='r2')
        search.fit(X_train, y_train)
        model = search.best_estimator_
    # evaluate on X_test, keep best by R²
joblib.dump(best_model, "models/rainfall/best_model.joblib")
```

Model	Winner	Primary metric
Rainfall	Random Forest	R^2 0.5676
Drought	Ridge Regression	R^2 1.00
Heatwave	Gradient Boosting	F1 0.46
Crop Impact	Random Forest	R^2 0.44

6. Testing & Metrics

6.1 Rainfall

Model	R^2	RMSE	MAE
Linear Regression	0.5484	60.46	38.03
Random Forest	**0.5676**	**59.16**	**35.85**
Gradient Boosting	0.5338	61.43	38.69

Interpretation: Captures monsoon peaks well; higher variance in dry spells or localized extremes.

6.2 Drought

Model	R^2	RMSE	MAE
Ridge Regression	**1.0000**	0.00	0.00
SVR	1.0000	0.08	0.08
Random Forest	1.0000	0.12	0.06

6.3 Heatwave

Model	Accuracy	F1
Logistic Regression	0.9014	0.25
Random Forest	0.9795	0.44
Gradient Boosting	**0.9808**	**0.4615**

Interpretation: High accuracy from class imbalance.

6.4 Crop Impact

Model	R^2	RMSE	MAE
Lasso	0.15	15.88	12.70
Decision Tree	0.28	14.65	10.55
Random Forest	**0.4396**	**12.92**	**9.59**

7. Hyperparameter Tuning & Improvements

Model	Next steps
Rainfall	Add ENSO/IOD indices; try XGBoost or LSTM for multi-step forecast.
Drought	Add satellite SMI/NDVI for real-time moisture/vegetation.
Heatwave	SMOTE for class balance; add wind and pressure anomalies.
Crop	NDVI; pest/market variables.

Re-run experiments:

`python models/rainfall/experiment_rainfall.py` (and similarly `experiment_drought.py`, `experiment_heatwave.py`, `experiment_crop.py`).

8. API Details

- **Base:** FastAPI; interactive docs at `GET /docs`.
- **Models:** Loaded from `models/<name>/best_model.joblib`; preprocessing (scaling/encoding) is in pipelines or applied in endpoints.

Endpoint	Method	Purpose
`/`	GET	Serves dashboard (index.html)
`/predict_rainfall`	POST	Monthly rainfall (mm) and risk category
`/predict_drought`	POST	Drought score 0–100 and category
`/predict_heatwave`	POST	Binary heatwave + probability
`/predict_crop_impact`	POST	Yield deviation % and impact category

Request / response (concise)

- **Rainfall:** `lag_1`, `lag_2`, `lag_3`, `lag_12` (float), `month` (1–12). Response: `predicted_rainfall_mm`, `risk_category` (e.g. High Risk (Flooding), Normal, Low Risk (Drought)).
- **Drought:** `rolling_3mo_avg`, `rolling_6mo_avg`, `deficit_pct`, `prev_year_drought`, `monsoon_strength`. Response: `drought_score`, `category` (No/Mild/Moderate/Severe/Extreme Drought).
- **Heatwave:** `max_temp_lag1`, `max_temp_lag2`, `max_temp_lag3`, `humidity`, `month`. Response: `is_heatwave`, `heatwave_probability`.
- **Crop:** `crop_type`, `state`, `season`, `rainfall`, `rainfall_anomaly`, `fertilizer_per_area`, `pesticide_per_area`. Response: `yield_deviation_pct`, `impact_category`, `available_crops`.

9. Real Testing Examples & Expected Results

Rainfall

Scenario	Input (excerpt)	Expected
Monsoon peak (July)	`lag_1=150, lag_2=100, lag_3=80, lag_12=200, month=7`	High rainfall (150–250 mm), monsoon peak
Winter dry (Dec)	`lag_1=10, lag_2=20, lag_3=50, lag_12=5, month=12`	Low rainfall (<30 mm)
Pre-monsoon (May)	`lag_1=30, lag_2=10, lag_3=5, lag_12=25, month=5`	Low–moderate (20–60 mm)

Heatwave

Scenario	Input (excerpt)	Expected
Extreme heat May	`max_temp_lag1=44, lag2=43, lag3=42, humidity=20, month=5`	High probability (>80%), heatwave alert
Normal April	`max_temp_lag1=36, lag2=35, lag3=34, humidity=45, month=4`	Low probability (<30%)

Crop

Scenario	Input (excerpt)	Expected
Rice – drought year	`crop_type=Rice, rainfall=600, rainfall_anomaly=-30, state=Andhra Pradesh, season=Kharif`	~12.5% yield reduction, severe
Cotton – normal	`crop_type=Cotton(lint), rainfall=900, rainfall_anomaly=0, state=Karnataka, season=Kharif`	Mild (5–15% deviation)

10. Dashboard Integration

Summary:

Model	Dashboard role
Rainfall	Primary monthly forecast; feeds risk overlays and summary.
Drought	Drought Assessment card; alerts and policy-oriented view.
Heatwave	Heatwave probability gauge; public health alerts when thresholds are crossed.
Crop	Crop Impact Analysis card; scenario-based yield deviation.