Goal: We aim to uncover long-term trends, seasonal patterns, and anomalies in India's rainfall data. We will examine historical rainfall trends, detect years with extreme or deficient rainfall, explore relationships between seasonal and annual rainfall, and forecast future rainfall using time series models

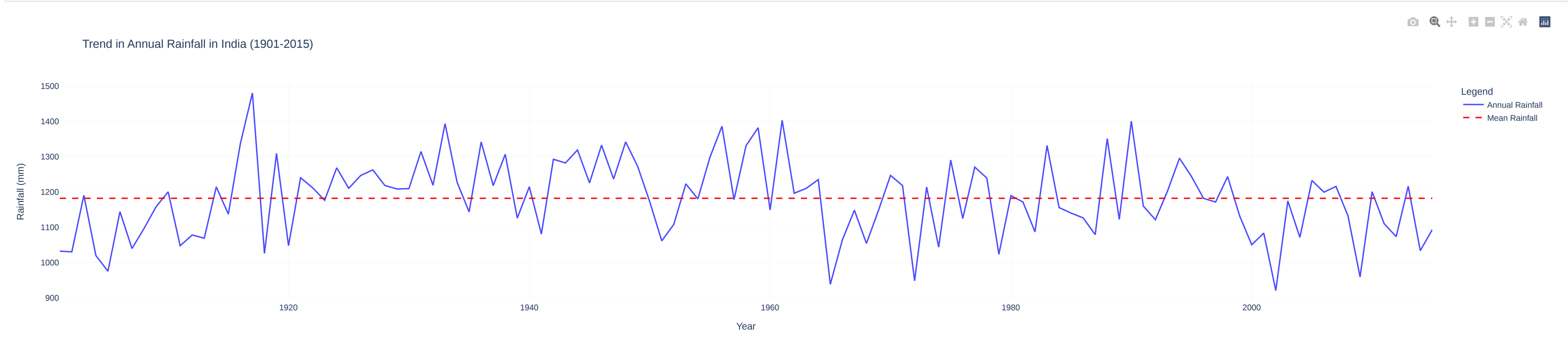
Loading Data

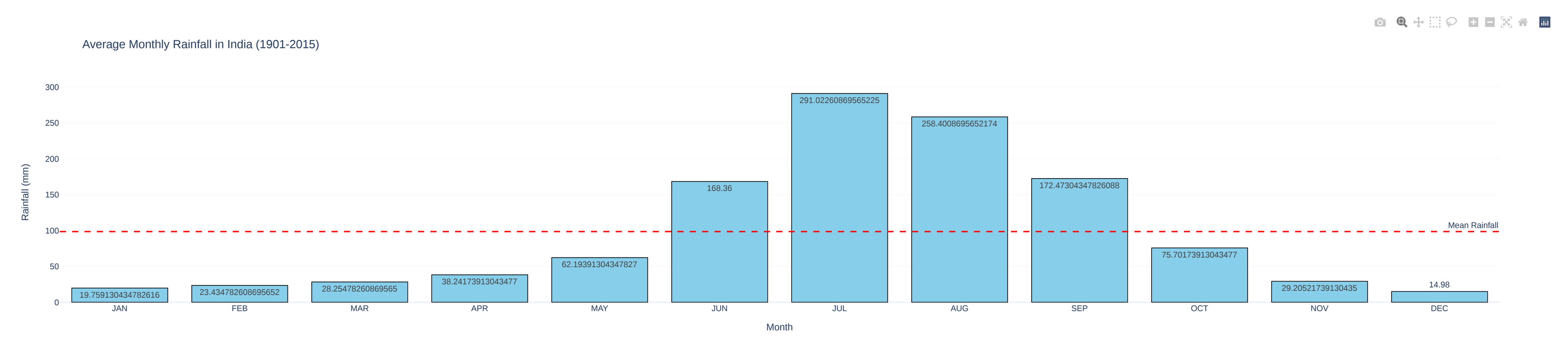
In [1]:
```python
import pandas as pd

rainfall_data = pd.read_csv("rainfall_wt_India_1901-2015.csv")

print(rainfall_data.head())
```

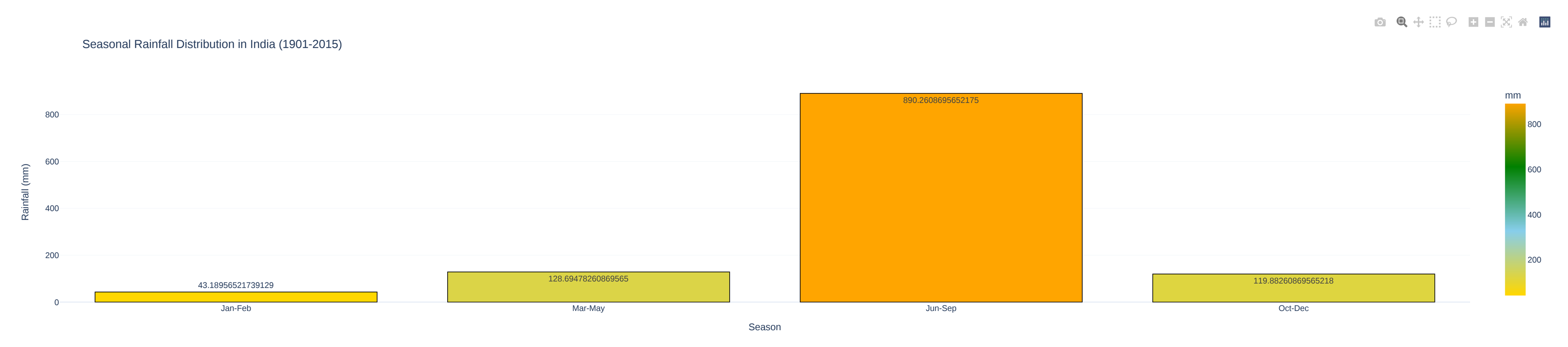
```
  REGION  YEAR   JAN   FEB   MAR   APR   MAY    JUN    JUL    AUG    SEP  \
0  INDIA  1901  34.7  37.7  18.0  39.3  50.8  113.4  242.2  272.9  124.4
1  INDIA  1902   7.4   4.3  19.0  43.5  48.3  108.8  284.0  199.7  201.5
2  INDIA  1903  17.0   8.3  31.3  17.1  59.5  118.3  297.0  270.4  199.1
3  INDIA  1904  14.4   9.6  31.8  33.1  72.4  164.8  261.0  206.4  129.6
4  INDIA  1905  25.3  20.9  42.7  33.7  55.7   93.3  252.8  200.8  178.4

     OCT   NOV   DEC  ANNUAL  Jan-Feb  Mar-May  Jun-Sep  Oct-Dec
0   52.7  38.0   8.3  1032.3     72.4    108.1    752.8     99.0
1   61.5  27.9  24.4  1030.2     11.7    110.8    794.0    113.8
2  117.9  36.9  17.7  1190.5     25.3    107.9    884.8    172.5
3   69.0  11.2  16.3  1019.8     24.0    137.4    761.8     96.6
4   51.4   9.7  10.5   975.3     46.2    132.2    725.4     71.6
```

Analyzing Annual Rainfall Trends Over Time

In [2]:
```python
import plotly.graph_objects as go
import plotly.express as px

annual_rainfall = rainfall_data[['YEAR', 'ANNUAL']]

fig_annual = go.Figure()
fig_annual.add_trace(go.Scatter(
    x=annual_rainfall['YEAR'],
    y=annual_rainfall['ANNUAL'],
    mode='lines',
    name='Annual Rainfall',
    line=dict(color='blue', width=2),
    opacity=0.7
))
fig_annual.add_trace(go.Scatter(
    x=annual_rainfall['YEAR'],
    y=[annual_rainfall['ANNUAL'].mean()] * len(annual_rainfall),
    mode='lines',
    name='Mean Rainfall',
    line=dict(color='red', dash='dash')
))
fig_annual.update_layout(
    title='Trend in Annual Rainfall in India (1901-2015)',
    xaxis_title='Year',
    yaxis_title='Rainfall (mm)',
    template='plotly_white',
    legend=dict(title="Legend"),
    height=500
)
fig_annual.show()

monthly_columns = ['JAN', 'FEB', 'MAR', 'APR', 'MAY', 'JUN', 'JUL', 'AUG', 'SEP', 'OCT', 'NOV', 'DEC']
monthly_avg = rainfall_data[monthly_columns].mean()

highest_rainfall_month = monthly_avg.idxmax()
lowest_rainfall_month = monthly_avg.idxmin()

fig_monthly = px.bar(
    x=monthly_avg.index,
    y=monthly_avg.values,
    labels={'x': 'Month', 'y': 'Rainfall (mm)'},
    title='Average Monthly Rainfall in India (1901-2015)',
    text=monthly_avg.values
)
fig_monthly.add_hline(
    y=monthly_avg.mean(),
    line_dash="dash",
    line_color="red",
    annotation_text="Mean Rainfall",
    annotation_position="top right"
)
fig_monthly.update_traces(marker_color='skyblue', marker_line_color='black', marker_line_width=1)
fig_monthly.update_layout(template='plotly_white', height=500)
fig_monthly.show()

seasonal_columns = ['Jan-Feb', 'Mar-May', 'Jun-Sep', 'Oct-Dec']
seasonal_avg = rainfall_data[seasonal_columns].mean()

fig_seasonal = px.bar(
    x=seasonal_avg.index,
    y=seasonal_avg.values,
    labels={'x': 'Season', 'y': 'Rainfall (mm)'},
    title='Seasonal Rainfall Distribution in India (1901-2015)',
    text=seasonal_avg.values,
    color=seasonal_avg.values,
    color_continuous_scale=['gold', 'skyblue', 'green', 'orange']
)

fig_seasonal.update_traces(marker_line_color='black', marker_line_width=1)
fig_seasonal.update_layout(
    template='plotly_white',
    height=500,
    coloraxis_colorbar=dict(title='mm')
)
fig_seasonal.update_layout(template='plotly_white', height=500)
fig_seasonal.show()
```



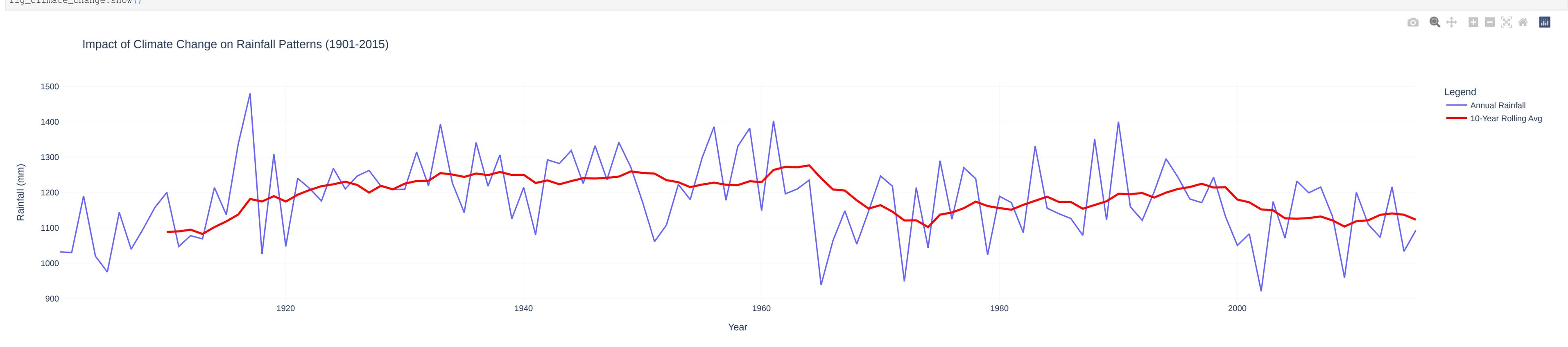




The graphs depict significant variability in India's annual rainfall, with no clear long-term trend over the century, as the annual rainfall oscillates around the mean (red dashed line). Peaks and troughs highlight extreme rainfall and dry years. A bar chart reveals an uneven monthly rainfall distribution, with July and August receiving the highest rainfall, while most months fall below the mean monthly rainfall, except during the monsoon season (June to September). The seasonal analysis underscores the monsoon's dominance, contributing around 890 mm, while other seasons (January-February, March-May, and October-December) provide comparatively minimal rainfall, highlighting the monsoon's critical role in India's climate.

Assessing the Impact of Climate Change in the Rainfall Trends in India

In [3]:
```python
rainfall_data['10-Year Rolling Avg'] = rainfall_data['ANNUAL'].rolling(window=10).mean()

fig_climate_change = go.Figure()

fig_climate_change.add_trace(go.Scatter(
    x=rainfall_data['YEAR'],
    y=rainfall_data['ANNUAL'],
    mode='lines',
    name='Annual Rainfall',
    line=dict(color='blue', width=2),
    opacity=0.6
))

fig_climate_change.add_trace(go.Scatter(
    x=rainfall_data['YEAR'],
    y=rainfall_data['10-Year Rolling Avg'],
    mode='lines',
    name='10-Year Rolling Avg',
    line=dict(color='red', width=3)
))

fig_climate_change.update_layout(
    title='Impact of Climate Change on Rainfall Patterns (1901-2015)',
    xaxis_title='Year',
    yaxis_title='Rainfall (mm)',
    template='plotly_white',
    legend=dict(title="Legend"),
    height=500
)

fig_climate_change.show()
```



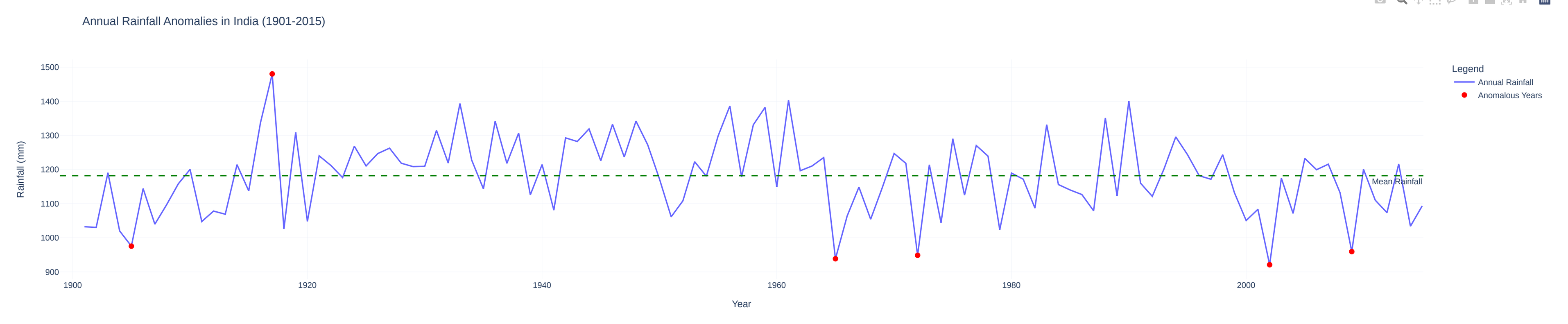
The graph displays India's annual rainfall trends (blue line) alongside a 10-year rolling average (red line) to highlight long-term patterns. While annual rainfall shows significant variability, the 10-year average reveals a slight downward trend since 1960, hinting at potential climate change impacts on rainfall distribution. Early 20th-century periods had higher averages, contrasting with more stable but lower averages in recent decades.

In [4]:
```python
from scipy.stats import pearsonr

mean_rainfall = rainfall_data['ANNUAL'].mean()
std_dev_rainfall = rainfall_data['ANNUAL'].std()

drought_years = rainfall_data[rainfall_data['ANNUAL'] < (mean_rainfall - 1.5 * std_dev_rainfall)]
extreme_rainfall_years = rainfall_data[rainfall_data['ANNUAL'] > (mean_rainfall + 1.5 * std_dev_rainfall)]

seasonal_columns = ['Jan-Feb', 'Mar-May', 'Jun-Sep', 'Oct-Dec']
seasonal_correlations = {
    season: pearsonr(rainfall_data[season], rainfall_data['ANNUAL'])[0] for season in seasonal_columns
}

drought_years_summary = drought_years[['YEAR', 'ANNUAL']].reset_index(drop=True)
extreme_rainfall_years_summary = extreme_rainfall_years[['YEAR', 'ANNUAL']].reset_index(drop=True)
seasonal_correlations_summary = pd.DataFrame.from_dict(seasonal_correlations, orient='index', columns=['Correlation'])

drought_years_summary, extreme_rainfall_years_summary, seasonal_correlations_summary
```

Out[4]:
```
(   YEAR  ANNUAL
 0  1905   975.3
 1  1965   938.4
 2  1972   948.5
 3  2002   920.8
 4  2009   959.3,
    YEAR  ANNUAL
 0  1917  1480.3
 1  1933  1393.5
 2  1956  1386.2
 3  1959  1382.1
 4  1961  1403.0
 5  1988  1351.0
 6  1990  1400.6,
          Correlation
 Jan-Feb     0.228913
 Mar-May     0.313057
 Jun-Sep     0.930027
 Oct-Dec     0.531648)
```

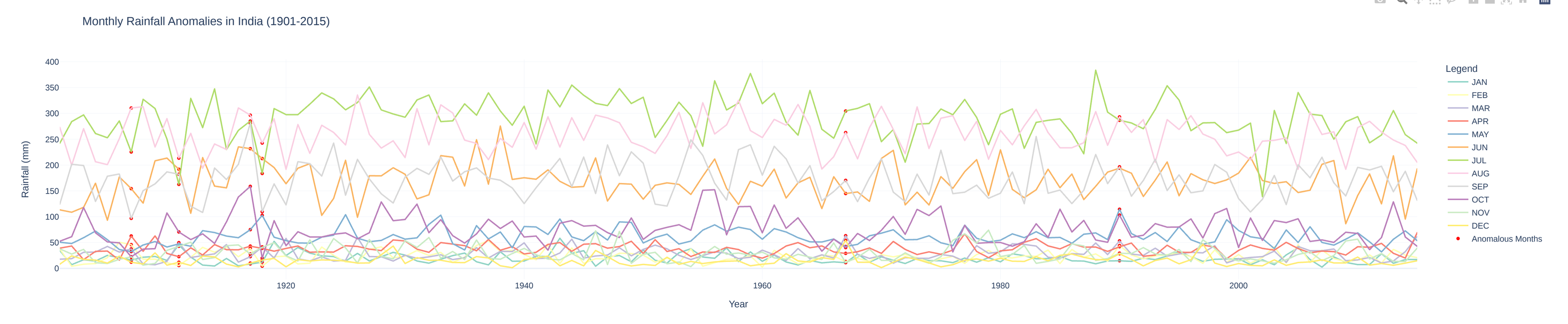
Detecting Anomalies in the Rainfall Trends in India

In [5]:
```python
from sklearn.ensemble import IsolationForest

isolation_forest = IsolationForest(contamination=0.05, random_state=42)
rainfall_data['Annual_Anomaly'] = isolation_forest.fit_predict(rainfall_data[['ANNUAL']])

annual_anomalies = rainfall_data[rainfall_data['Annual_Anomaly'] == -1]

monthly_data = rainfall_data[['JAN', 'FEB', 'MAR', 'APR', 'MAY', 'JUN', 'JUL', 'AUG', 'SEP', 'OCT', 'NOV', 'DEC']]
monthly_anomalies = isolation_forest.fit_predict(monthly_data)

rainfall_data['Monthly_Anomaly'] = monthly_anomalies
monthly_anomalies_df = rainfall_data[rainfall_data['Monthly_Anomaly'] == -1][['YEAR'] + monthly_columns]

fig_annual_anomalies = go.Figure()

fig_annual_anomalies.add_trace(go.Scatter(
    x=rainfall_data['YEAR'],
    y=rainfall_data['ANNUAL'],
    mode='lines',
    name='Annual Rainfall',
    line=dict(color='blue', width=2),
    opacity=0.6
))

fig_annual_anomalies.add_trace(go.Scatter(
    x=annual_anomalies['YEAR'],
    y=annual_anomalies['ANNUAL'],
    mode='markers',
    name='Anomalous Years',
    marker=dict(color='red', size=8, symbol='circle')
))

fig_annual_anomalies.add_hline(
    y=rainfall_data['ANNUAL'].mean(),
    line_dash='dash',
    line_color='green',
    annotation_text='Mean Rainfall',
    annotation_position='bottom right'
)

fig_annual_anomalies.update_layout(
    title='Annual Rainfall Anomalies in India (1901-2015)',
    xaxis_title='Year',
    yaxis_title='Rainfall (mm)',
    template='plotly_white',
    legend=dict(title="Legend"),
    height=500
)

fig_annual_anomalies.show()
```



Above graph highlights years with significant rainfall anomalies, where annual rainfall deviated substantially from the mean. Drought years (e.g., 1905, 1965, 2002) and extreme rainfall years (e.g., 1917, 1961) are marked as red points, which showcase outliers in rainfall patterns. While most years cluster around the mean (green dashed line), the anomalies emphasize the variability in India's rainfall, driven by factors like monsoonal fluctuations and climate events. This underscores the need for monitoring and preparedness for extreme weather events.

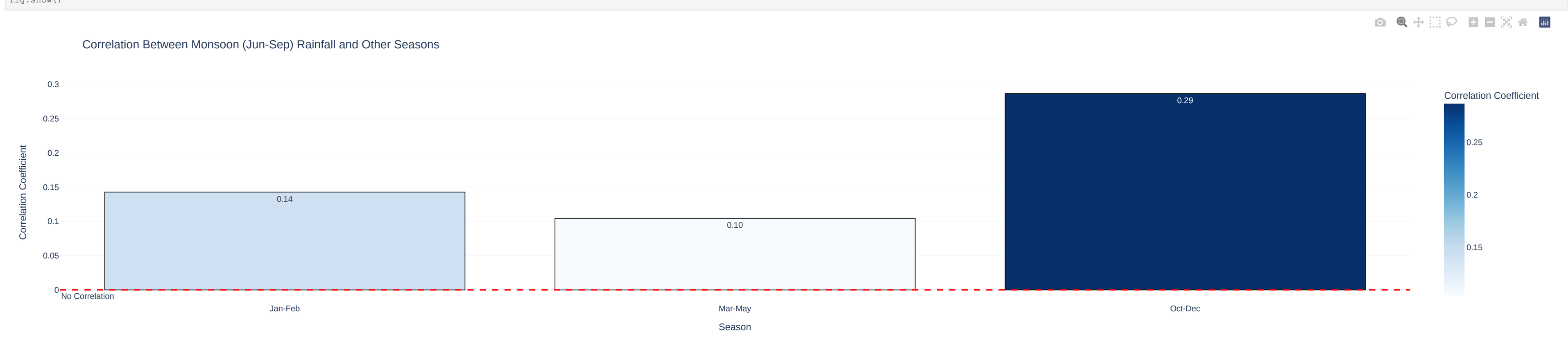
In [6]:
```python
monthly_anomalies = []
for column in monthly_columns:
    for _, row in monthly_anomalies_df.iterrows():
        monthly_anomalies.append({'Year': row['YEAR'], 'Month': column, 'Rainfall': row[column]})

monthly_anomalies_df_long = pd.DataFrame(monthly_anomalies)

fig_monthly_anomalies = px.line(
    rainfall_data,
    x='YEAR',
    y=monthly_columns,
    labels={'YEAR': 'Year', 'value': 'Rainfall (mm)', 'variable': 'Month'},
    title='Monthly Rainfall Anomalies in India (1901-2015)',
    color_discrete_sequence=px.colors.qualitative.Set3
)

fig_monthly_anomalies.add_trace(go.Scatter(
    x=monthly_anomalies_df_long['Year'],
    y=monthly_anomalies_df_long['Rainfall'],
    mode='markers',
    name='Anomalous Months',
    marker=dict(color='red', size=5, symbol='circle')
))

fig_monthly_anomalies.update_layout(
    template='plotly_white',
    legend=dict(title="Legend"),
    height=500
)

fig_monthly_anomalies.show()
```



The variability is most pronounced during the monsoon months (June to September), which reflects the critical role of these months in India's rainfall dynamics. Anomalies in non-monsoon months, while less frequent, highlight periods of unusual weather patterns, potentially linked to climate variability or regional disturbances. This graph underscores the uneven distribution and high dependence on monsoonal rainfall for India's water resources.

Correlating Seasonal Rainfall with Annual Totals

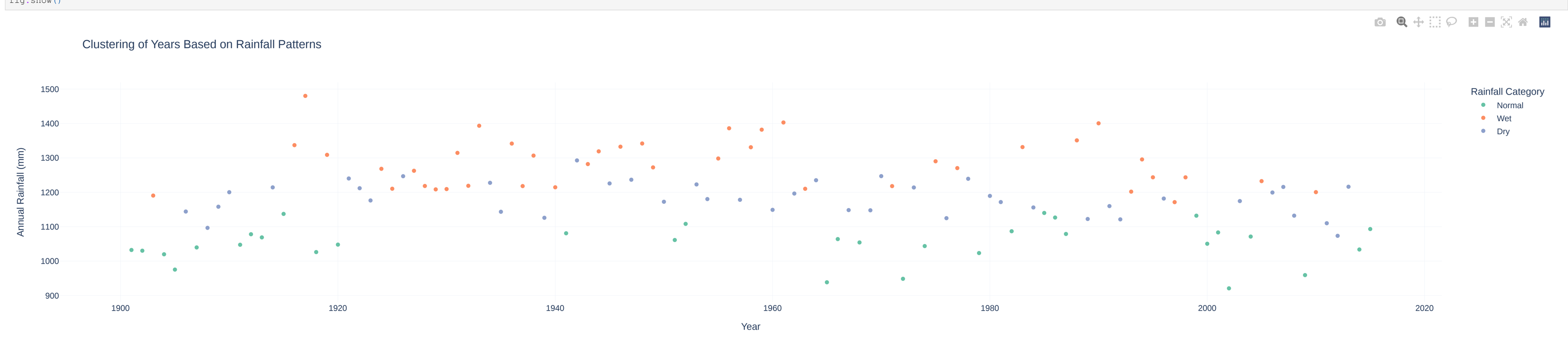
In [7]:
```python
seasonal_columns = ['Jan-Feb', 'Mar-May', 'Jun-Sep', 'Oct-Dec']
monsoon_column = 'Jun-Sep'
relationships = {}

for season in seasonal_columns:
    if season != monsoon_column:
        corr, _ = pearsonr(rainfall_data[monsoon_column], rainfall_data[season])
        relationships[season] = corr

correlation_data = pd.DataFrame({
    'Season': list(relationships.keys()),
    'Correlation Coefficient': list(relationships.values())
})

fig = px.bar(
    correlation_data,
    x='Season',
    y='Correlation Coefficient',
    title='Correlation Between Monsoon (Jun-Sep) Rainfall and Other Seasons',
    labels={'Season': 'Season', 'Correlation Coefficient': 'Correlation Coefficient'},
    text='Correlation Coefficient',
    color='Correlation Coefficient',
    color_continuous_scale='Blues'
)

fig.add_hline(
    y=0,
    line_dash="dash",
    line_color="red",
    annotation_text="No Correlation",
    annotation_position="bottom left"
)

fig.update_traces(marker_line_color='black', marker_line_width=1, texttemplate='%{text:.2f}')
fig.update_layout(
    template='plotly_white',
    height=500
)

fig.show()
```



The graph shows the correlation between monsoon rainfall and rainfall during other seasons. The October-December season has the highest correlation (0.29), which suggests a moderate relationship, possibly due to the post-monsoon retreat rains. The January-February (0.14) and March-May (0.10) seasons exhibit weaker correlations, which indicate minimal dependence on monsoon rainfall. This highlights the dominance of monsoonal patterns as an independent driver of India's annual rainfall, with limited spillover effects on other seasons.

Grouping Years Based on Rainfall Patterns

In [8]:
```python
from sklearn.cluster import KMeans
from sklearn.preprocessing import StandardScaler

rainfall_features = rainfall_data[['Jan-Feb', 'Mar-May', 'Jun-Sep', 'Oct-Dec', 'ANNUAL']]
scaler = StandardScaler()
scaled_features = scaler.fit_transform(rainfall_features)

kmeans = KMeans(n_clusters=3, random_state=42, n_init=10)
rainfall_data['Rainfall_Cluster'] = kmeans.fit_predict(scaled_features)

cluster_labels = {0: 'Dry', 1: 'Normal', 2: 'Wet'}
rainfall_data['Rainfall_Category'] = rainfall_data['Rainfall_Cluster'].map(cluster_labels)

fig = px.scatter(
    rainfall_data,
    x='YEAR',
    y='ANNUAL',
    color='Rainfall_Category',
    title='Clustering of Years Based on Rainfall Patterns',
    labels={'YEAR': 'Year', 'ANNUAL': 'Annual Rainfall (mm)', 'Rainfall_Category': 'Rainfall Category'},
    color_discrete_sequence=px.colors.qualitative.Set2,
    hover_data={'Rainfall_Cluster': True, 'Rainfall_Category': True}
)

fig.update_layout(
    template='plotly_white',
    legend_title='Rainfall Category',
    height=500
)

fig.show()
```

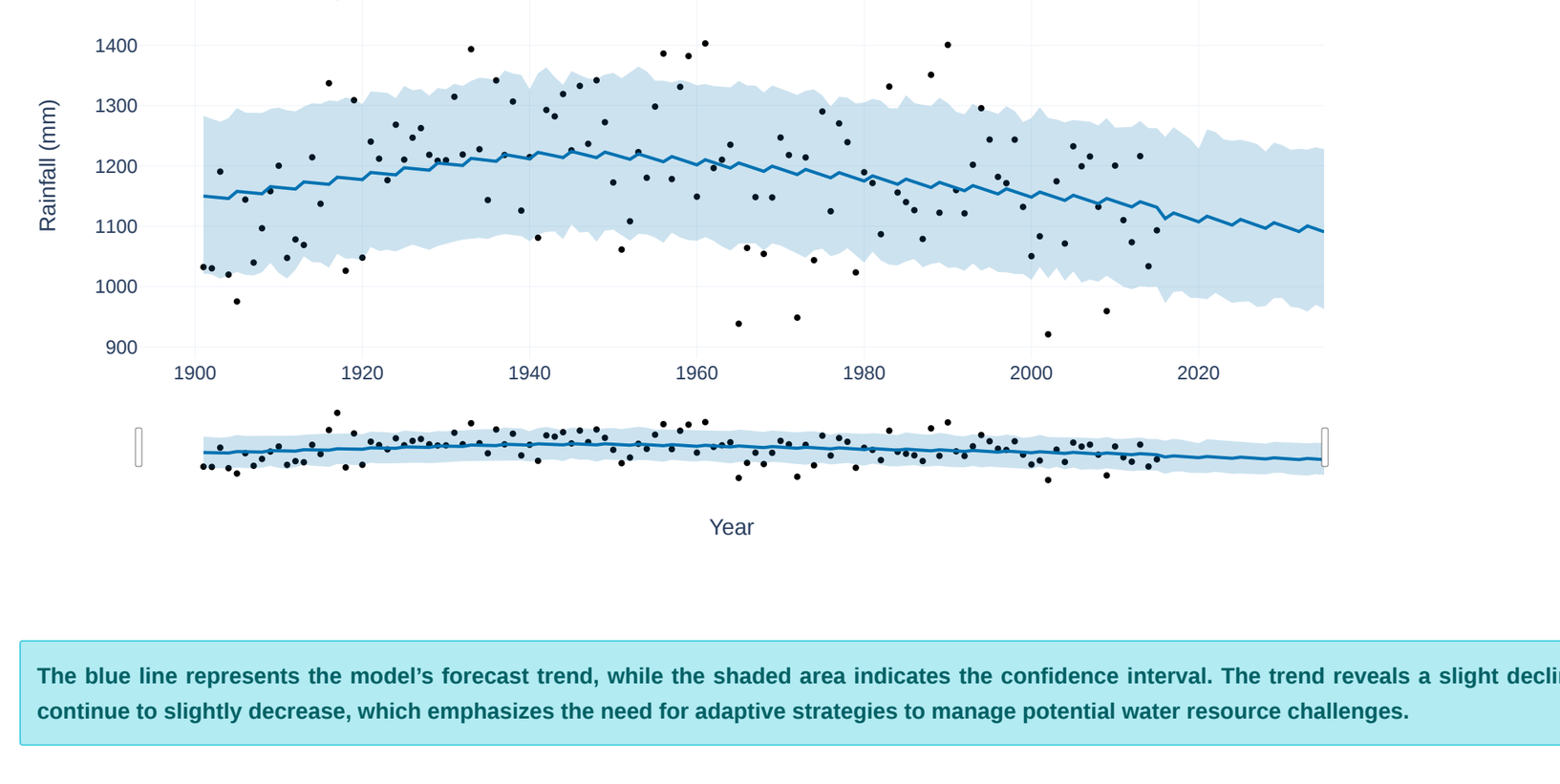


The clusters reveal that most years fall into the Normal category, while Wet years (above-normal rainfall) are sporadically distributed throughout the timeline, with a concentration in the early and mid-20th century. Dry years (below-normal rainfall) are more frequent in the latter half of the timeline, which indicates a potential shift in rainfall patterns over time. This clustering emphasizes the variability and potential long-term changes in India's rainfall dynamics.

Forecasting Future Rainfall

In [9]:
```python
rainfall_data['DATE'] = pd.to_datetime(rainfall_data['YEAR'], format='%Y')
annual_rainfall_ts = rainfall_data.set_index('DATE')['ANNUAL']

# use: pip install prophet

from prophet import Prophet
# Prepare the data for Prophet
prophet_data = annual_rainfall_ts.reset_index()
prophet_data.columns = ['ds', 'y']

from prophet.plot import plot_plotly, plot_components_plotly

prophet_model = Prophet()
prophet_model.fit(prophet_data)

# create a future dataframe for the next 20 years
future = prophet_model.make_future_dataframe(periods=20, freq='Y')
forecast = prophet_model.predict(future)

fig_forecast = plot_plotly(prophet_model, forecast)

fig_forecast.update_layout(
    title='Annual Rainfall Forecast Using Prophet',
    xaxis_title='Year',
    yaxis_title='Rainfall (mm)',
    template='plotly_white',
    height=500
)

fig_forecast.show()
```

```
13:45:59 - cmdstanpy - INFO - Chain [1] start processing
13:45:59 - cmdstanpy - INFO - Chain [1] done processing
```



The blue line represents the model's forecast trend, while the shaded area indicates the confidence interval. The trend reveals a slight decline in annual rainfall over time, with notable year-to-year variability (black dots representing actual data points). The model captures the variability well but highlights that future rainfall may continue to slightly decrease, which emphasizes the need for adaptive strategies to manage potential water resource challenges.

Conclusion

The analysis of India's rainfall trends and patterns from 1901 to 2015 reveals significant variability in annual and seasonal rainfall, with the monsoon season (June-September) being the dominant contributor. Anomalous years of extreme drought and wetness highlight the unpredictability of rainfall, while clustering shows a shift towards more dry years in recent decades. Correlations indicate the limited dependency of non-monsoon seasons on monsoon rainfall. A time-series forecast using Prophet suggests a slight declining trend in annual rainfall, which emphasises the need for long-term water resource planning and adaptation to changing climate patterns.

In [ ]: