Analyzing and Forecasting Rainfall (Monthly Avg) using statistical methods and Machine Learning.

The Excel file has 02 sheets (Avg and SE). Avg is the average value of the concerned parameter while SE has the standard error associated with the average value. The file has monthly time series data from Jan 1990 to Dec 2022. The parameter in column B is rainfall (consider as Y), while indices from column C to K affect rainfall over a region (consider as X). Details of parameters from columns C to K are:

- RH_%: Relative humidity (in %)
- Dew_Point_°C: Dew point temperature (in °C)
- Cloud_Amount_%: Cloud cover fraction (in %)
- Air_T_°C: Air temperature (in °C)
- WS_m/s: Wind speed (in m/s)
- SWR_W/m2: Shortwave radiation (in W/m2)
- Soil_Mois_cum/cum: Soil moisture in the top 10 cm of soil (in cu.m/cu.m)
- Air_Pres_Pa: Air pressure (in Pa)
- ET_mm/month: Evapotranspiration (in mm/month)
- **Training dataset: 01 Jan 1990 to 31 Dec 2013**
- **Validation dataset: 01 Jan 2014 to 31 Dec 2022**

We are exploring the possibilities of rainfall prediction using the SVM and random forest and other models. The preferred model performance indicators to use are

- RMSE
- MAE (mean absolute error), and
- MAPE (mean absolute percentage error).

In [1]:
```
#Import necessary py libraries
import os, sys
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
```

```
#to ignore warnings
import warnings
warnings.filterwarnings('ignore')
```

In [2]:
```
import statsmodels.api as sm
from statsmodels.graphics.tsaplots import plot_acf
from statsmodels.tsa.stattools import adfuller
from statsmodels.tsa.seasonal import seasonal_decompose
from sklearn.metrics import mean_squared_error


import itertools
```

In [3]:
```
# # Dependency for excel read (One time)
# !pip install openpyxl
```

In [4]:
```
# Check working directory/ set working directory/ set input folder path

path = "P:\\IT\\Rainfall-TS-Sep2023"
print("Current working directory is set as:", path)
file_path = path+'\\input'
print("Input files are under the folder:", file_path)

#List files under input folder
os.listdir(file_path)
```

```
Current working directory is set as: P:\IT\Rainfall-TS-Sep2023
Input files are under the folder: P:\IT\Rainfall-TS-Sep2023\input
```

Out[4]:
```
['Data_Rainfall_Prediction_USGCM.xlsx']
```

In [5]:
```
Avg = file_path+"\\Data_Rainfall_Prediction_USGCM.xlsx"


# Read the input files

df_Avg = pd.read_excel(file_path +"\\Data_Rainfall_Prediction_USGCM.xlsx", sheet_na
df_SE = pd.read_excel(file_path +"\\Data_Rainfall_Prediction_USGCM.xlsx", sheet_nam
```

Descriptive Analytics on Dataset

In [6]:
```
df_Avg
```

Out[6]:

	Month-year	Rain_mm	RH_%	Dew_Point_°C	Cloud_Amount_%	Air_T_°C	WS_m/s
0	1990-01-01	9.014030	29.964444	-1.340000	28.943333	19.730960	5.889429
1	1990-02-01	31.475803	42.185556	4.015556	54.024444	20.425801	4.589979
2	1990-03-01	17.078917	30.737778	3.087778	44.677778	24.333952	4.742352
3	1990-04-01	2.704660	17.756667	1.768889	36.974444	31.297905	6.420676
4	1990-05-01	16.200781	26.618889	12.231111	70.660000	35.571863	4.477367
...	...	...	...	...	...	...	...
391	2022-08-01	188.385804	77.000000	24.718889	81.926667	29.007510	5.162503
392	2022-09-01	253.565665	78.410000	24.028889	60.655556	28.283159	4.383535
393	2022-10-01	127.415645	76.618889	19.396667	30.790000	24.708316	3.156706
394	2022-11-01	0.031965	69.993333	12.811111	16.972222	20.459165	3.518426
395	2022-12-01	2.372392	60.513333	6.810000	23.676667	16.920918	4.033786

396 rows × 11 columns

In [7]:

```
df_SE
```

Out[7]:

	Month-year	Rain_mm	RH_%	Dew_Point_°C	Cloud_Amount_%	Air_T_°C	WS_m/s	SW
0	1990-01-01	0.079583	0.644994	0.214437	2.472732	0.061176	0.031627	
1	1990-02-01	0.398202	1.197770	0.098645	0.968860	0.076334	0.022232	
2	1990-03-01	0.145088	2.034543	0.553396	0.936011	0.084061	0.006031	
3	1990-04-01	0.107626	0.820369	0.276428	2.190209	0.064854	0.009983	
4	1990-05-01	0.317898	0.337711	0.151982	2.110934	0.024254	0.005593	
...	...	...	...	...	...	...	...	
391	2022-08-01	1.540608	2.176294	0.260520	0.954321	0.032938	0.020541	
392	2022-09-01	1.721940	2.057870	0.272690	2.969574	0.033339	0.014663	
393	2022-10-01	0.838470	0.530787	0.206868	0.935739	0.015943	0.008677	
394	2022-11-01	0.012082	0.961290	0.193358	2.510118	0.018776	0.017732	
395	2022-12-01	0.095602	1.457933	0.433490	1.929064	0.032802	0.027817	

396 rows × 11 columns

In [8]:

```
df_Avg.describe()
```

Out[8]:

	Month-year	Rain_mm	RH_%	Dew_Point_°C	Cloud_Amount_%	Air_
count	396	396.000000	396.000000	396.000000	396.000000	396.000
mean	2006-06-16 13:56:21.818181760	75.453002	47.464167	11.262910	45.307045	26.70
min	1990-01-01 00:00:00	0.000000	8.403333	-6.104444	5.965556	14.004
25%	1998-03-24 06:00:00	7.205603	29.853611	3.116944	28.865278	21.211
50%	2006-06-16 00:00:00	17.302752	44.607778	8.945000	41.230556	27.614
75%	2014-09-08 12:00:00	128.241655	65.521389	21.187222	61.312778	31.52
max	2022-12-01 00:00:00	465.058800	87.320000	25.921111	92.045556	37.84
std	NaN	104.863389	21.234400	9.378826	22.013287	6.21

In [9]:

```
df_Avg.corr()
```

Out[9]:

	Month-year	Rain_mm	RH_%	Dew_Point_°C	Cloud_Amount_%	Air_
Month-year	1.000000	0.048172	0.155573	0.119657	-0.061645	-0.03
Rain_mm	0.048172	1.000000	0.727830	0.817442	0.799042	0.30
RH_%	0.155573	0.727830	1.000000	0.799814	0.424880	-0.14
Dew_Point_°C	0.119657	0.817442	0.799814	1.000000	0.688347	0.45
Cloud_Amount_%	-0.061645	0.799042	0.424880	0.688347	1.000000	0.50
Air_T_°C	-0.032683	0.300009	-0.142170	0.459805	0.501925	1.00
WS_m/s	-0.108719	0.072354	-0.394333	-0.087703	0.336223	0.46
SWR_W/m2	-0.131904	-0.029835	-0.451631	0.092514	0.233488	0.86
Soil_Mois_cum/cum	0.119205	0.818991	0.934725	0.849203	0.526675	0.06
Air_Pres_Pa	0.021967	-0.631598	-0.197367	-0.705230	-0.754324	-0.89
ET_mm/month	0.065483	0.767379	0.879845	0.761668	0.443870	-0.01

In [10]:

```
df_Avg.shape
```

Out[10]: (396, 11)

In [11]:
```
df_Avg.isna().sum()
```

Out[11]:
```
Month-year          0
Rain_mm             0
RH_%                0
Dew_Point_°C        0
Cloud_Amount_%      0
Air_T_°C            0
WS_m/s              0
SWR_W/m2            0
Soil_Mois_cum/cum   0
Air_Pres_Pa         0
ET_mm/month         0
dtype: int64
```

In [12]:
```
df_Avg.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 396 entries, 0 to 395
Data columns (total 11 columns):
 #   Column             Non-Null Count  Dtype
---  ------             --------------  -----
 0   Month-year         396 non-null    datetime64[ns]
 1   Rain_mm            396 non-null    float64
 2   RH_%               396 non-null    float64
 3   Dew_Point_°C       396 non-null    float64
 4   Cloud_Amount_%     396 non-null    float64
 5   Air_T_°C           396 non-null    float64
 6   WS_m/s             396 non-null    float64
 7   SWR_W/m2           396 non-null    float64
 8   Soil_Mois_cum/cum  396 non-null    float64
 9   Air_Pres_Pa        396 non-null    float64
 10  ET_mm/month        396 non-null    float64
dtypes: datetime64[ns](1), float64(10)
memory usage: 34.2 KB
```

Key observations on rainfall data from Descriptive analysis

- Rows, cols = (396, 11)
- DateTime is index column
- Rest are float
- 2 Parameters with negative corr wrt rainfall (rest are positive)
    1. SWR_W/m2: Shortwave radiation (in W/m2)
    2. Air_Pres_Pa: Air pressure (in Pa)
- No NULL value

Clean data sample! Good data collection and cleaning job!! :) Nothing to be done here.

Let's dig deep to analyse timeseries properties

In [13]:
```
#Some data prep
data= df_Avg.copy() #Create a copy before transformations, we can always fallback t
#data
# spliting date
data['year'] = data['Month-year'].dt.year
data['month'] = data['Month-year'].dt.month
data.rename(columns={'Month-year':'date'}, inplace=True)
data.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 396 entries, 0 to 395
Data columns (total 13 columns):
 #   Column             Non-Null Count  Dtype
---  ------             --------------  -----
 0   date               396 non-null    datetime64[ns]
 1   Rain_mm            396 non-null    float64
 2   RH_%               396 non-null    float64
 3   Dew_Point_°C       396 non-null    float64
 4   Cloud_Amount_%     396 non-null    float64
 5   Air_T_°C           396 non-null    float64
 6   WS_m/s             396 non-null    float64
 7   SWR_W/m2           396 non-null    float64
 8   Soil_Mois_cum/cum  396 non-null    float64
 9   Air_Pres_Pa        396 non-null    float64
 10  ET_mm/month        396 non-null    float64
 11  year               396 non-null    int32
 12  month              396 non-null    int32
dtypes: datetime64[ns](1), float64(10), int32(2)
memory usage: 37.3 KB
```

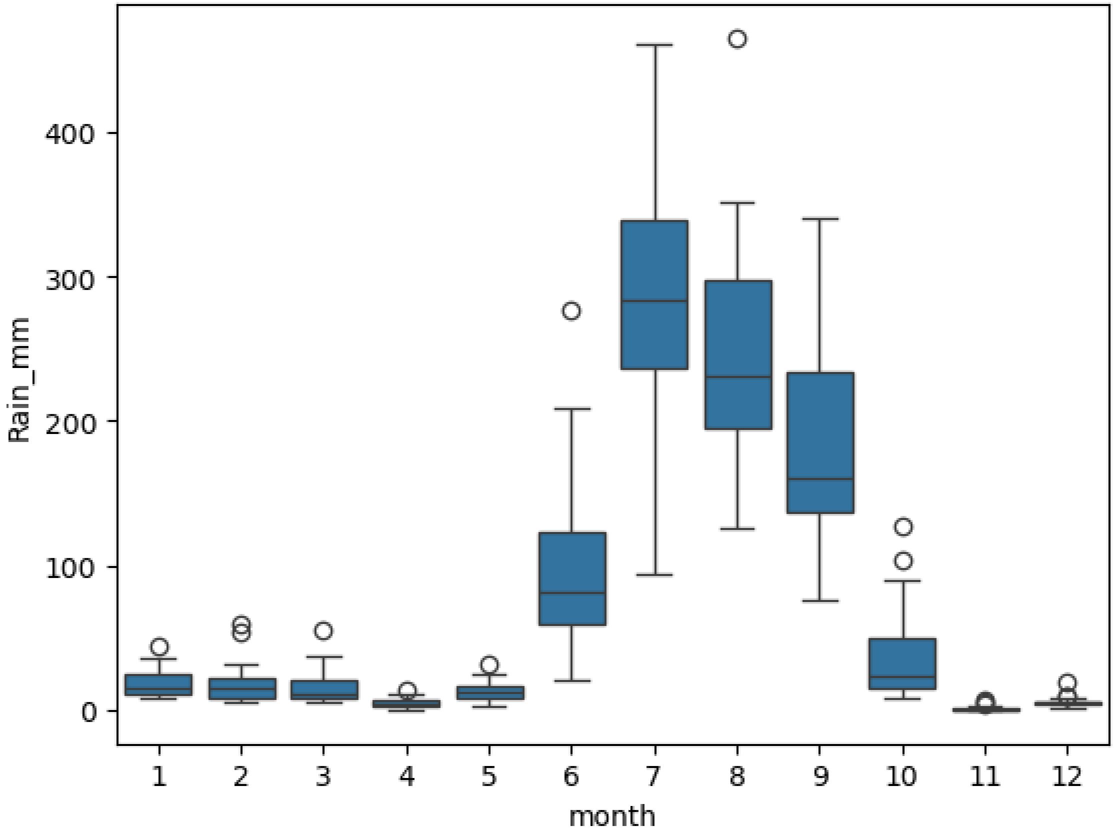
Plotting Line plot for Time Series data

Please note that data is already re-sampled to Monthly average. Since, the volume column is of continuous data type, we will use line graph to visualize it. As it's 'Rain Data' we expect it to have seasonality.

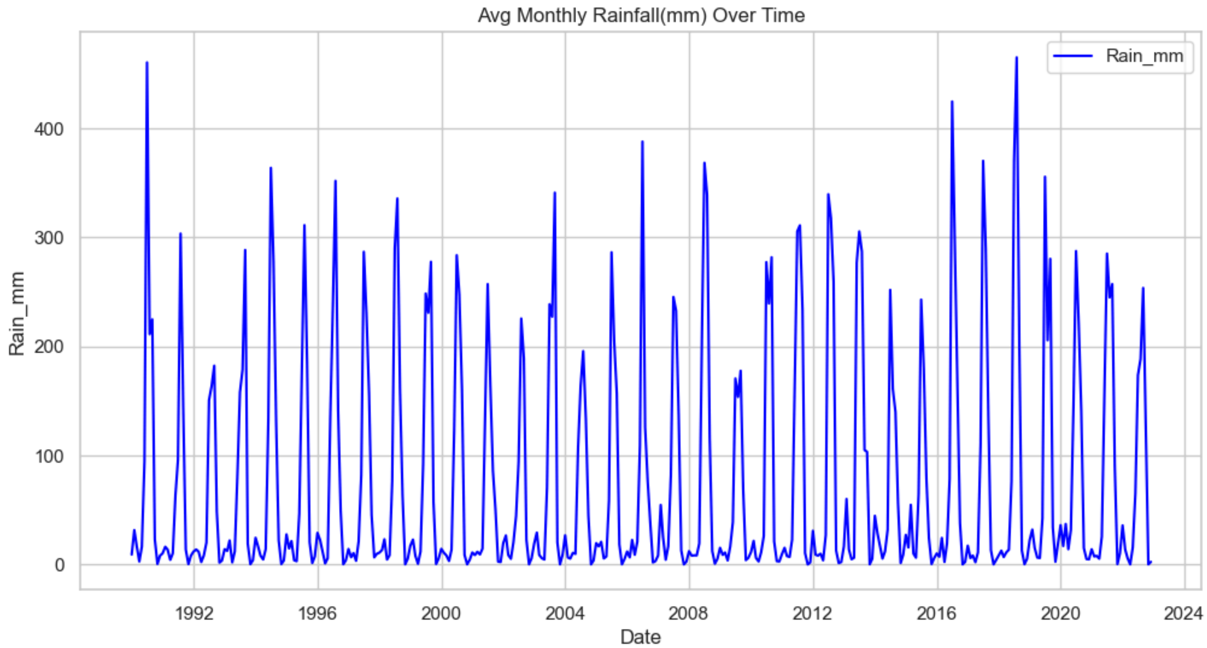
In [14]:
```
# # If 'Date' is a column, but not the index, you can set it as the index
data.set_index('date', inplace=True)
```

In [15]:
```
#See Monthly Patterns
sns.boxplot(x="month", y="Rain_mm", data=data)
#Yes, monsoon!
```

Out[15]: <Axes: xlabel='month', ylabel='Rain_mm'>

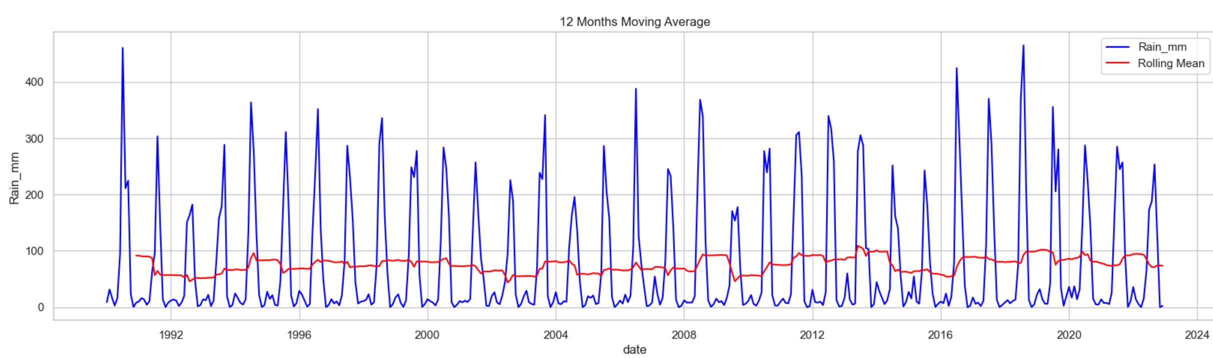


In [16]:
```
# Assuming df is your DataFrame
sns.set(style="whitegrid") # Setting the style to whitegrid for a clean background

plt.figure(figsize=(12, 6)) # Setting the figure size
sns.lineplot(data=data, x='date', y='Rain_mm', label='Rain_mm', color='blue')

# Adding labels and title
plt.xlabel('Date')
plt.ylabel('Rain_mm')
plt.title('Avg Monthly Rainfall(mm) Over Time')

plt.show()
```



In [17]:
```
#12-M Moving Average

plt.figure(figsize=(20,5))
twelve_months_moving_average = data['Rain_mm'].rolling(window=12).mean()
sns.lineplot(data=data, x='date', y='Rain_mm', label='Rain_mm', color='blue')
plt.plot(twelve_months_moving_average, color='red', label='Rolling Mean')
plt.legend(loc='best')
plt.title('12 Months Moving Average')
```

Out[17]: Text(0.5, 1.0, '12 Months Moving Average')



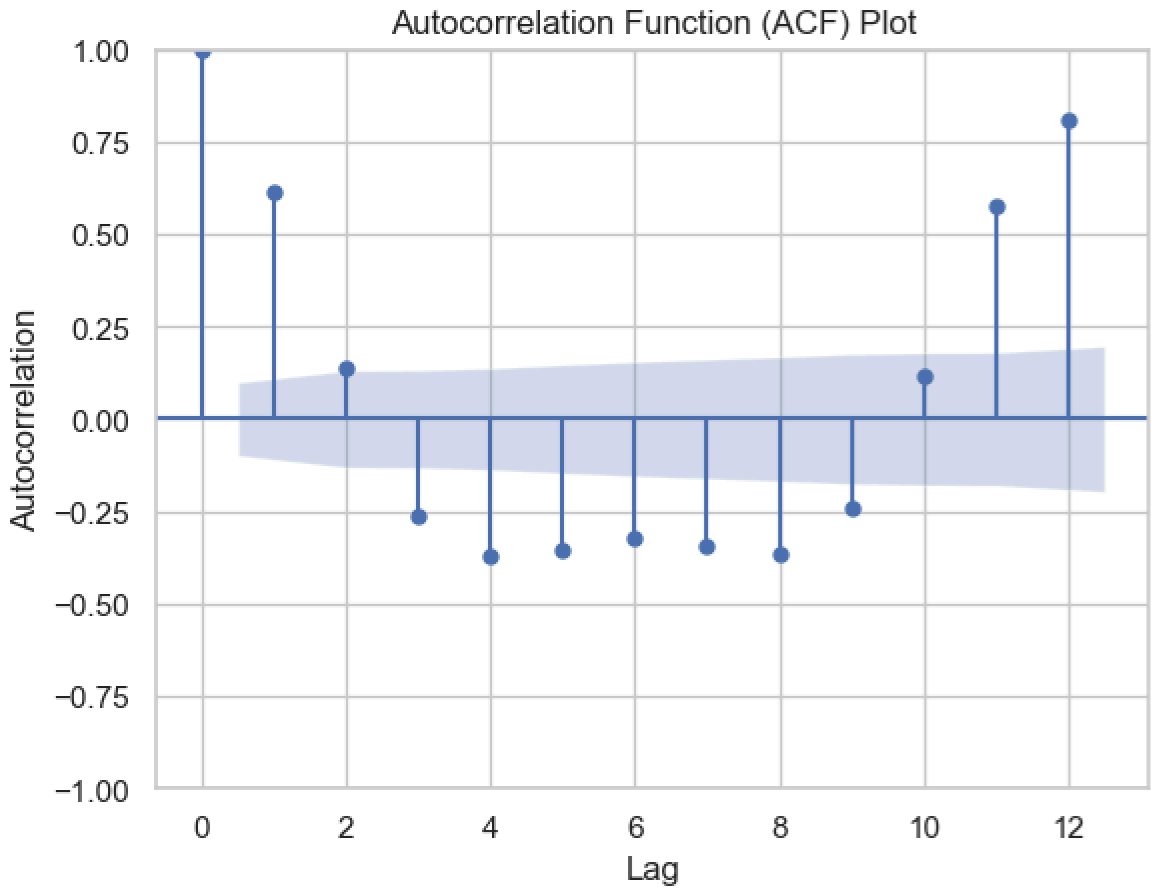
Detecting Seasonality Using Auto Correlation

We will detect Seasonality using the autocorrelation function (ACF) plot. Peaks at regular intervals in the ACF plot suggest the presence of seasonality.

In [18]:
```
# Plot the ACF
plt.figure(figsize=(18, 6))
plot_acf(data['Rain_mm'], lags=12)  # As it is monthly data, a lag of 12 would repr
plt.xlabel('Lag')
plt.ylabel('Autocorrelation')
```

```
plt.title('Autocorrelation Function (ACF) Plot')
plt.show()
```

```
<Figure size 1800x600 with 0 Axes>
```



We can see that we have **Seasonality** in our monthly data. (Data is also cyclic: Try lag in multiples of 12 to see visual evidence. It show resets evey 12 months.)

Detecting Stationarity

We will perform the ADF test to formally test for stationarity.

The test is based on:

- Null hypothesis that a unit root is present in the time series, indicating that the series is non-stationary.
- The alternative hypothesis is that the series is stationary after differencing (i.e., it has no unit root).
- The ADF test employs an augmented regression model that includes lagged differences of the series to determine the presence of a unit root.

In [19]:
```
# Assuming df is your DataFrame
result = adfuller(data['Rain_mm'])
print('ADF Statistic:', result[0])
```

```
print('p-value:', result[1])
print('Critical Values:', result[4])
```

```
ADF Statistic: -4.2623600913855775
p-value: 0.0005158194038950781
Critical Values: {'1%': -3.4475850438570115, '5%': -2.869135963767125, '10%': -2.570
8164748773332}
```

Based on the

- ADF Stat < all Critical Values.
- p-value**: 0.0005158194038950781

So, **we accept the Alternate hypothesis and conclude that the data appear to be stationary** according to the *Augmented Dickey-Fuller test*.

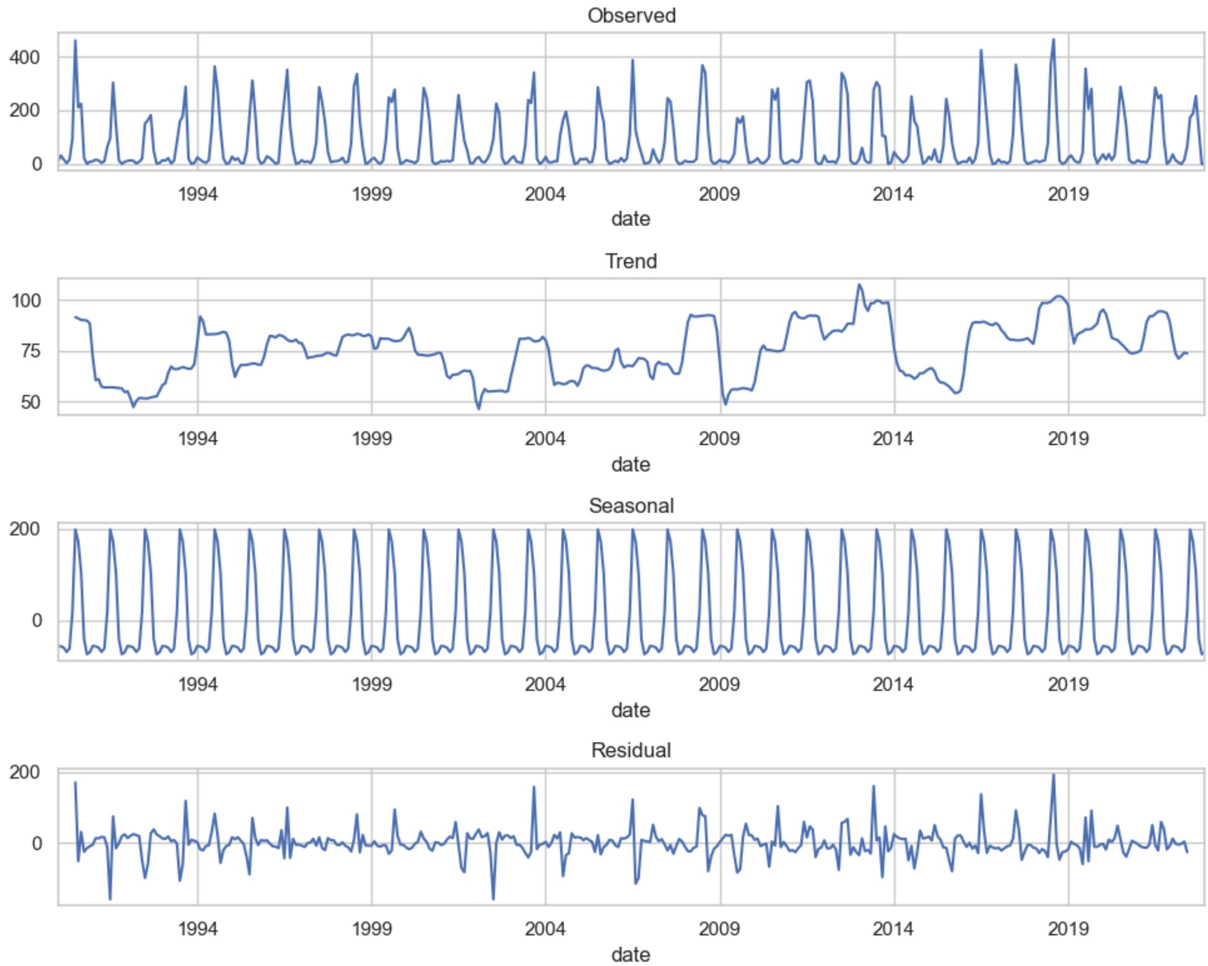
- This suggests that differencing or other transformations may NOT be needed to achieve stationarity before applying certain time series models

- D-F Test we want p-value** < 0.05 to reject its null hypothesis. Based on the test which been done before, we can comfortably say that our training data is stationary.

Decompose TS

In [20]:
```
# Decompose the time series using the seasonal_decompose function
decomposition = seasonal_decompose(data['Rain_mm'], model='additive', period=12)
```

In [21]:
```
# Plot the decomposed components
fig, axes = plt.subplots(4, 1, figsize=(10, 8))
decomposition.observed.plot(ax=axes[0], title='Observed')
decomposition.trend.plot(ax=axes[1], title='Trend')
decomposition.seasonal.plot(ax=axes[2], title='Seasonal')
decomposition.resid.plot(ax=axes[3], title='Residual')
plt.tight_layout()
plt.show()
```



Let's make some Models

In [22]:
```
#Prepare Target
Y = data['Rain_mm']
#Y

#Prepare features

features = list(data.select_dtypes(include = np.number).columns)
#features.remove('Rain_mm')
# Features to remove
to_remove = ['Rain_mm','day','year', 'month']

# Removing non-feature cols from list
features = [f for f in features if f not in to_remove]

#print(features)
#Features to exog (For Sarimax)
exog = data[features]
```

In [ ]:
```
```

1. SARIMAX Model

SARIMA extends ARIMA's capabilities to handle seasonal patterns. SARIMAX further enhances the model's predictive accuracy by incorporating exogenous variables. X= Multivariate

In [23]:
```
from statsmodels.tsa.statespace.sarimax import SARIMAX
```

In [24]:
```
# Parameter definition for best model selection, we will use AIC as model metric -

# Define the p, d and q parameters to take any value between 0 and 2
p = d = q = range(0, 2)

# Generate all different combinations of p, d and q triplets
pdq = list(itertools.product(p, d, q))

# Generate all different combinations of seasonal p, q and q triplets
seasonal_pdq = [(x[0], x[1], x[2], 12) for x in list(itertools.product(p, d, q))]

#Initiate AIC Score

AIC_scores_list = []

#pdq
#seasonal_pdq
```

In [25]:
```
#Run all the combinations to find the best fit
best_aic = np.inf
best_pdq = None
best_seasonal_pdq = None
temp_model = None

for param in pdq:
    for param_seasonal in seasonal_pdq:
        temp_model = SARIMAX(Y,exog=exog,order = param,seasonal_order = param_seaso
        results = temp_model.fit()
        l = []
        l.append(param[0])
        l.append(param[1])
        l.append(param[2])
        l.append(param_seasonal[0])
        l.append(param_seasonal[1])
        l.append(param_seasonal[2])
        l.append(param_seasonal[3])
        l.append(results.aic)
        AIC_scores_list.append(l)
        if results.aic < best_aic:
            best_aic = results.aic
            best_pdq = param
            best_seasonal_pdq = param_seasonal


print("Best SARIMAX{}x{}12 model - AIC:{}".format(best_pdq, best_seasonal_pdq, best
```

```
J:\anaconda3\envs\torch\Lib\site-packages\statsmodels\tsa\base\tsa_model.py:473: Val
ueWarning: No frequency information was provided, so inferred frequency MS will be u
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Warning: Maximum Likelihood optimization failed to converge. Check mle_retvals
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Best SARIMAX(1, 1, 1)x(0, 1, 1, 12)12 model - AIC:3689.0420654543386
```

In [26]:

```
#Best model per last RUN: Best SARIMAX(1, 1, 1)x(0, 1, 1, 12)12 model - AIC:3689.04


AIC_scores = pd.DataFrame.from_records(AIC_scores_list)
AIC_scores.columns=['p', 'd', 'q', 'P', 'D', 'Q', 's', 'AIC']
AIC_scores.iloc[AIC_scores['AIC'].argmin()]
```

Out[26]:
```
p         1.000000
d         1.000000
q         1.000000
P         0.000000
D         1.000000
Q         1.000000
s        12.000000
AIC    3689.042065
Name: 59, dtype: float64
```

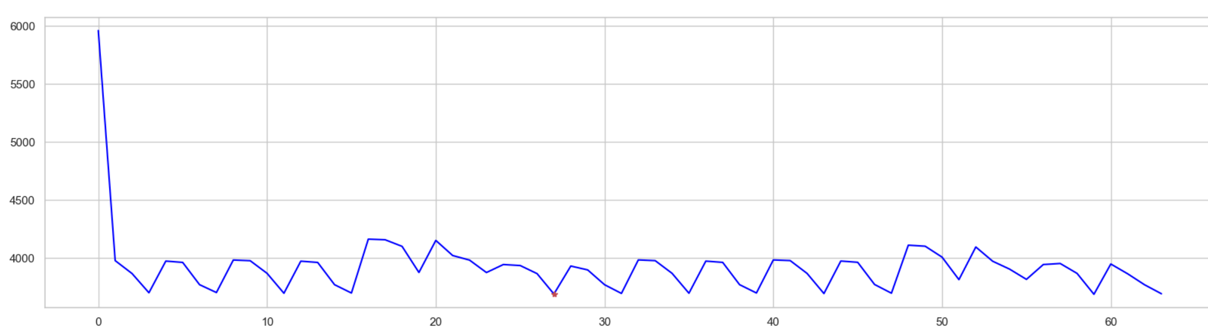
In [27]:
```
#See more AIC Details
AIC_scores.head(10)
```

Out[27]:

	p	d	q	P	D	Q	s	AIC
0	0	0	0	0	0	0	12	5959.356574
1	0	0	0	0	0	1	12	3978.815216
2	0	0	0	0	1	0	12	3867.553978
3	0	0	0	0	1	1	12	3702.143812
4	0	0	0	1	0	0	12	3974.839772
5	0	0	0	1	0	1	12	3963.453628
6	0	0	0	1	1	0	12	3771.757969
7	0	0	0	1	1	1	12	3704.062952
8	0	0	1	0	0	0	12	3983.967866
9	0	0	1	0	0	1	12	3978.087918

In [28]:
```
plt.figure(figsize=(20,5))
plt.plot(AIC_scores.AIC, color='blue')
plt.plot(27, AIC_scores.AIC[27], 'r*')
```

Out[28]: [<matplotlib.lines.Line2D at 0x172ac89c0d0>]



In [29]:
```
print(best_pdq)
print(best_seasonal_pdq)
```

```
(1, 1, 1)
(0, 1, 1, 12)
```

AIC Analysis: Best Model Selection

After fitting the data with different combination of models, we got the best parameters as following:

```
* p = 1, d = 1, q = 1
* P = 0, D = 1, Q = 1
* s = 12
```

Run Best Model

In [30]:
```
best_model = SARIMAX(Y,
                     exog=exog,
                     order = best_pdq,
                     seasonal_order = best_seasonal_pdq,
                     enforce_stationarity=True,
                     enforce_invertibility=True)
results = best_model.fit()
```

```
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Warning: Maximum Likelihood optimization failed to converge. Check mle_retvals
  warnings.warn("Maximum Likelihood optimization failed to "
```

In [31]:
```
#See results
print(results.summary().tables[0])
```

```
                                     SARIMAX Results
==========================================================================================
======
Dep. Variable:                            Rain_mm   No. Observations:
396
Model:             SARIMAX(1, 1, 1)x(0, 1, 1, 12)   Log Likelihood                     -18
31.521
Date:                            Sun, 22 Sep 2024   AIC                                 36
89.042
Time:                                    20:17:04   BIC                                 37
40.367
Sample:                                01-01-1990   HQIC                                37
09.402
                                     - 12-01-2022
Covariance Type:                              opg
==========================================================================================
======
```

In [32]:
```
pred_dynamic = results.get_prediction(start=pd.to_datetime('2014-01-01'), dynamic=T
pred_dynamic_ci = pred_dynamic.conf_int()
```

In [33]:
```
y_pred = pred_dynamic.predicted_mean
```

In [34]:
```
y_test = Y['2014':]
```

In [35]:
```
import math
rmse = math.sqrt(((y_pred - y_test) ** 2).mean())
print('The Mean Squared Error of our predictions is {}'.format(round(mse, 4)))

#Last run RMSE: The Mean Squared Error of our predictions is 30.3417
```

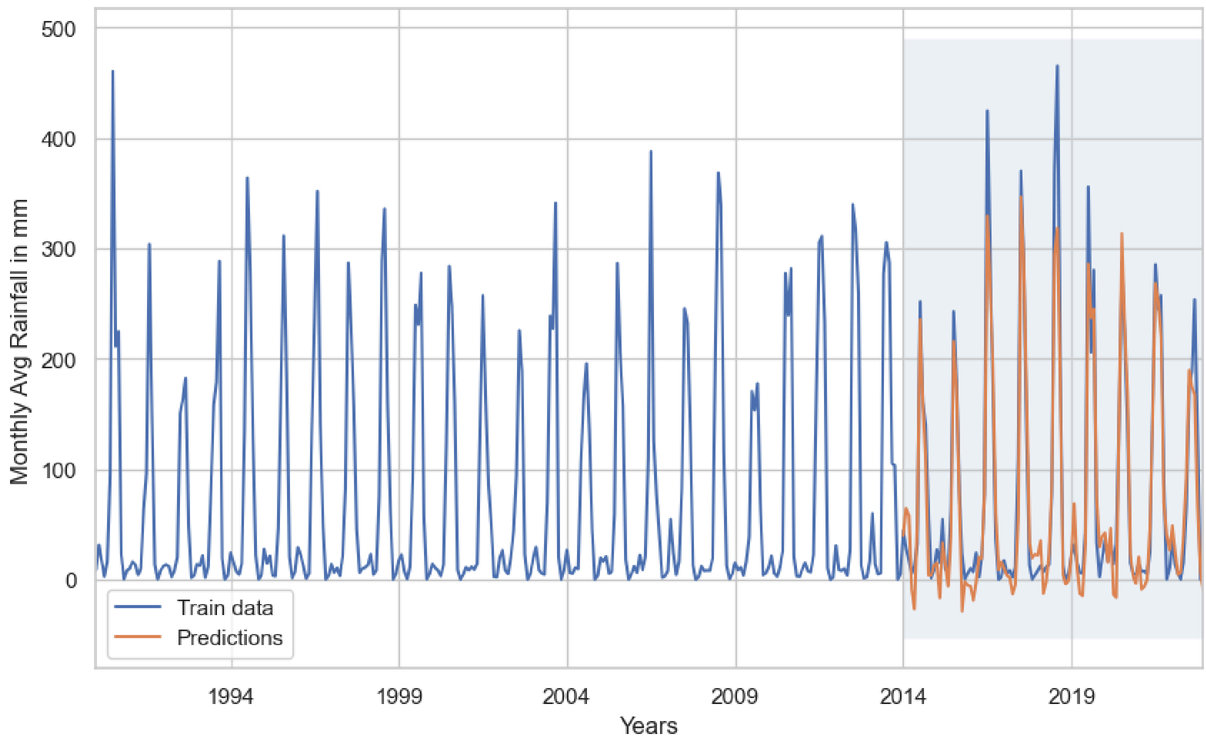
```
The Mean Squared Error of our predictions is 30.3417
```

In [38]:
```
# rmse = math.sqrt(mean_squared_error(y_test, y_pred))
# rmse
```

Out[38]:
```
30.341685122009853
```

In [36]:
```
# Plot the actual values.
axis_plt = Y['1985':].plot(label='Train data', figsize=(10, 6))

# Plot the predicted values.
pred_dynamic.predicted_mean.plot(ax=axis_plt, label='Predictions')

# Plot confidence values and fill it with some colour.
# axis_plt.fill_between(pred_dynamic_ci.index, pred_dynamic_ci.iloc[:, 0], pred_dyn
axis_plt.fill_betweenx(axis_plt.get_ylim(), pd.to_datetime('2014'), Y.index[-1], al

# Set labels.
axis_plt.set_xlabel('Years')
axis_plt.set_ylabel('Monthly Avg Rainfall in mm')

# Put legend on the plot at the best place it fits.
plt.legend(loc='best')
```

Out[36]:
```
<matplotlib.legend.Legend at 0x1729505ca10>
```


500
400
300
200
100
0
Monthly Avg Rainfall in mm
Train data
Predictions
1994
1999
2004
2009
2014
2019
Years

In [ ]: