Indian Railways: A Comprehensive Geospatial and Data Analysis

This project showcases an extensive exploration of the Indian Railways dataset, prepared and analyzed by Turya Ganguly. It offers unique insights into one of the world's largest railway networks through advanced data analytics and geospatial techniques.

Key Highlights of the Project:

Exploratory Data Analysis (EDA):

- Detailed analysis of railway zones, station distributions, and operational insights.
- Extraction and analysis of key attributes like station names, codes, and zones for meaningful insights.

Geospatial Analysis:

- Mapping the geographic spread of railway stations across India.
- Integration of railway station data with state boundaries for state-wise insights.

Visualization:

- Creation of detailed visual representations of the railway network overlaid on India's administrative map.
- Highlighting station densities, zone demarcations, and spatial overlaps.

Data Cleaning & Preparation:

- Handling invalid and missing geometries to ensure data quality.
- Transforming spatial data into valid GeoDataFrames for accurate analysis.

Tech Stack:

- Python libraries like Pandas, GeoPandas, and Matplotlib for data processing and visualization.
- Shapefiles for state boundaries and geospatial attributes.

This project provides an in-depth understanding of the Indian Railways, offering actionable insights for transportation planning, infrastructure development, and policy-making. It serves as an exemplar of how data-driven approaches can unravel the complexities of a massive and dynamic system.

IMPORT

```
#Import necessary Libraries
import os
import pandas as pd
import json
import geopandas as gpd
import plotly.express as px
import numpy  as np

import matplotlib.pyplot as plt
import seaborn as sns

from shapely.geometry import LineString, Point
```

LOAD FILE FUNCTIONS

Initialising shp filepath

```
shp_file_path = "/content/drive/MyDrive/Datasets/Indian Railway Dataset/India States/Indian_states.shp"
```

Function to read shp file

```
def read_shp(filename, data_path = shp_file_path):
    full_path = f'{data_path}/{filename}'

    if os.path.isfile(path=full_path):
        gdf = gpd.read_file(filename=full_path)
    else:
        print('Invalid path specified.')
        gdf = [None]
    return gdf
```

Reading stations.json

```
stations = pd.read_json('/content/drive/MyDrive/Datasets/Indian Railway Dataset/stations.json')
```

FETCH THE DATA

Function to convert JSON to GeodataFrame

```
def convert_to_gdf(json_data, geometry_type):

    if geometry_type == 'Point':
        gdf = gpd.GeoDataFrame.from_features(features=json_data['features'])

    elif (geometry_type == 'LineString'):
        # fetch the column names based on `properties` keys
        properties_columns = list(json_data['features'][0]['properties'].keys())
        # fetch the values (rows) based on the `properties` values
        properties_vals = [list(i['properties'].values()) for i in json_data['features']]


        geometry_col = [
            LineString(i['geometry']['coordinates'])
            if len(i['geometry']['coordinates']) >= 2
            # else Point(i['geometry']['coordinates'][0])
            else LineString([i['geometry']['coordinates'][0]] * 2)
            for i in json_data['features']
        ]

        df = pd.DataFrame(data=properties_vals, columns=properties_columns)
        df['geometry'] = geometry_col
        gdf = gpd.GeoDataFrame(df)

    # setting the CRS
    gdf = gdf.set_crs('EPSG:4326')

    return gdf
```

Converting stations.json to GeodataFrame and first 20 rows displayed

```
stations_gdf = convert_to_gdf(stations,'Point')
#stations_gdf.to_csv(get_file_path(csv_file_path,'stations.csv'),index=False)
stations_gdf.head()
```

	geometry	state	code	name	zone	address
0	POINT (75.45165 27.25206)	Rajasthan	BDHL	Badhal	NWR	Kishangarh Renwal, Rajasthan
1	None	None	XX-BECE	XX-BECE	None	None
2	None	None	XX-BSPY	XX-BSPY	None	None
3	None	None	YY-BPLC	YY-BPLC	None	None
4	POINT (79.51975 28.91343)	Uttar Pradesh	KHH	KICHHA	NER	Kichha, Uttar Pradesh

Loading trains.json

```
trains = pd.read_json('/content/drive/MyDrive/Datasets/Indian Railway Dataset/trains.json')
```

Validating trains.json

```
import requests
import json
import pandas as pd

# Step 1: Download the JSON file from Google Drive
file_id = '1mcfRfUVbnqwxh9WNDA_V8DYDFXe1hHE4'
url = f'https://docs.google.com/uc?export=download&id={file_id}'
```

```
response = requests.get(url)
if response.status_code == 200:
    json_content = response.content.decode('utf-8')
else:
    raise Exception(f'Error downloading file: {response.status_code}')

# Step 2: Validate the JSON structure
try:
    data = json.loads(json_content)
    print("JSON is valid.")
except json.JSONDecodeError as e:
    print(f"JSON is invalid: {e}")
    # Optionally, write the content to a file for manual inspection
    with open('invalid_json.json', 'w') as f:
        f.write(json_content)
    raise

# Step 3: Load the JSON into a DataFrame
try:
    df = pd.json_normalize(data)
    print("DataFrame loaded successfully.")
    print(df.head())
except Exception as e:
    print(f"Error loading DataFrame: {e}")
    raise
```

```
JSON is valid.
DataFrame loaded successfully.
                type                                           features
0  FeatureCollection  [{'geometry': {'type': 'LineString', 'coordina...
```

Converting trains.json into Geodataframe

```
trains_gdf = convert_to_gdf(trains,'LineString')
#trains_gdf.to_csv(get_file_path(csv_file_path,'trains.csv'), index=False)

trains_gdf.head()
```

	third_ac	arrival	from_station_code	name	zone	chair_car	first_class	duration_m	sleeper	from_station_name	...	ret
0	0	12:15:00	JAT	Jammu Tawi Udhampur Special	NR	0	0	35.0	0	JAMMU TAWI	...	
1	0	08:35:00	UHP	UDHAMPUR JAMMUTAWI DMU	NR	0	0	50.0	0	UDHAMPUR	...	
2	0	17:50:00	JAT	JAT UDAHMPUR DMU	NR	0	0	35.0	0	JAMMU TAWI	...	
3	0	19:50:00	UHP	UDHAMPUR JAMMUTAWI DMU	NR	0	0	30.0	0	UDHAMPUR	...	
4	1	12:30:00	BDTS	Mumbai BandraT-Bikaner SF Special	NWR	0	0	55.0	1	MUMBAI BANDRA TERMINUS	...	

5 rows × 22 columns

Loading schedules.json

```
schedules = pd.read_json('/content/drive/MyDrive/Datasets/Indian Railway Dataset/schedules.json')
```

```
schedules.head()
```

	arrival	day	train_name	station_name	station_code	id	train_number	departure
0	None	1.0	Falaknuma Lingampalli MMTS	KACHEGUDA FALAKNUMA	FM	302214	47154	07:55:00
1	None	1.0	Thrissur Guruvayur Passenger	THRISUR	TCR	281458	56044	18:55:00
2	None	1.0	Porbandar Muzaffarpur Express	PORBANDAR	PBR	309335	19269	15:05:00
3	None	1.0	RAIPUR ITWARI PASS	RAIPUR JN	R	283774	58205	13:30:00
4	None	1.0	Gomoh-Asansol MEMU	GOMOH JN	GMO	319937	63542	07:20:00

Loading shape files for Indian states

```
# Load the shapefile
states_ind = gpd.read_file('/content/drive/MyDrive/Datasets/Indian Railway Dataset/India States/Indian_states.shp')

# Display the first few rows
print(states_ind.head())
```

```
                     st_nm                                           geometry
0  Andaman & Nicobar Island  MULTIPOLYGON (((93.71976 7.20707, 93.71909 7.2...
1        Arunanchal Pradesh  POLYGON ((96.16261 29.38078, 96.1686 29.37432,...
2                     Assam  MULTIPOLYGON (((89.74323 26.30362, 89.7429 26....
3                     Bihar  MULTIPOLYGON (((84.5072 24.26323, 84.50355 24....
4               Chandigarh  POLYGON ((76.84147 30.75996, 76.83599 30.73623...
```

```
# Check the type of the object
print(type(states_ind))  # Should output: <class 'geopandas.geodataframe.GeoDataFrame'>
```

```
<class 'geopandas.geodataframe.GeoDataFrame'>
```

CLEAN THE DATA

Stations

```
stations_gdf.isna().sum()
```

	0
geometry	293
state	4532
code	0
name	0
zone	4532
address	4532

```
stations_gdf.columns
```

```
Index(['geometry', 'state', 'code', 'name', 'zone', 'address'], dtype='object')
```

```
stations_gdf.head()
```

	geometry	state	code	name	zone	address
0	POINT (75.45165 27.25206)	Rajasthan	BDHL	Badhal	NWR	Kishangarh Renwal, Rajasthan
1	None	None	XX-BECE	XX-BECE	None	None
2	None	None	XX-BSPY	XX-BSPY	None	None
3	None	None	YY-BPLC	YY-BPLC	None	None
4	POINT (79.51975 28.91343)	Uttar Pradesh	KHH	KICHHA	NER	Kichha, Uttar Pradesh

```
states_ind.head()
```

	st_nm	geometry
0	Andaman & Nicobar Island	MULTIPOLYGON (((93.71976 7.20707, 93.71909 7.2...
1	Arunanchal Pradesh	POLYGON ((96.16261 29.38078, 96.1686 29.37432,...
2	Assam	MULTIPOLYGON (((89.74323 26.30362, 89.7429 26....
3	Bihar	MULTIPOLYGON (((84.5072 24.26323, 84.50355 24....
4	Chandigarh	POLYGON ((76.84147 30.75996, 76.83599 30.73623...

```
states_ind.columns
```

```
Index(['st_nm', 'geometry'], dtype='object')
```

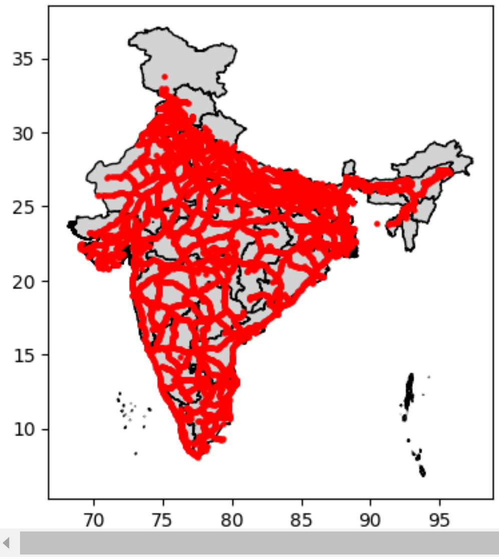
```
df_stations = gpd.sjoin(left_df=stations_gdf, right_df=states_ind,
                        predicate = 'intersects')
```

```
df_stations.head(20)
```

	geometry	state	code	name	zone	address	index_right	st_nm
0	POINT (75.45165 27.25206)	Rajasthan	BDHL	Badhal	NWR	Kishangarh Renwal, Rajasthan	26	Rajasthan
4	POINT (79.51975 28.91343)	Uttar Pradesh	KHH	KICHHA	NER	Kichha, Uttar Pradesh	32	Uttarakhand
5	POINT (74.43499 29.5552)	Rajasthan	SRKN	Sherekan	NWR	MDR 89, Rajasthan	26	Rajasthan
6	POINT (74.75103 29.23823)	Rajasthan	BKKA	Bhukarka	NWR	Bhukarka, Rajasthan	26	Rajasthan
7	POINT (74.77363 29.19256)	Rajasthan	NHR	Nohar	NWR	State Highway 36, Rajasthan	26	Rajasthan
8	POINT (80.23136 12.97522)	Tamil Nadu	PRGD	Perungudi	SR	Chennai, Tamil Nadu	28	Tamil Nadu
9	POINT (74.71796 29.34564)	Haryana	KNNA	Khinaniyan	NWR	State Highway 23, Haryana	26	Rajasthan
10	POINT (78.21668 21.83847)	None	JKR	JAULKHERA	None	None	17	Madhya Pradesh
11	POINT (78.03136 21.90981)	None	BYS	BARSALI	None	None	17	Madhya Pradesh
12	POINT (78.93631 23.83819)	None	GW	GIRWAR	None	None	17	Madhya Pradesh
13	POINT (79.01991 23.87177)	None	DGD	DANGIDHAR	None	None	17	Madhya Pradesh
14	POINT (75.10355 23.77074)	Madhya Pradesh	DOD	DHODHAR	WR	Dhodar, Madhya Pradesh	17	Madhya Pradesh
15	POINT (79.07463	None	GAJ	GANESHGANJ	None	None	17	Madhya

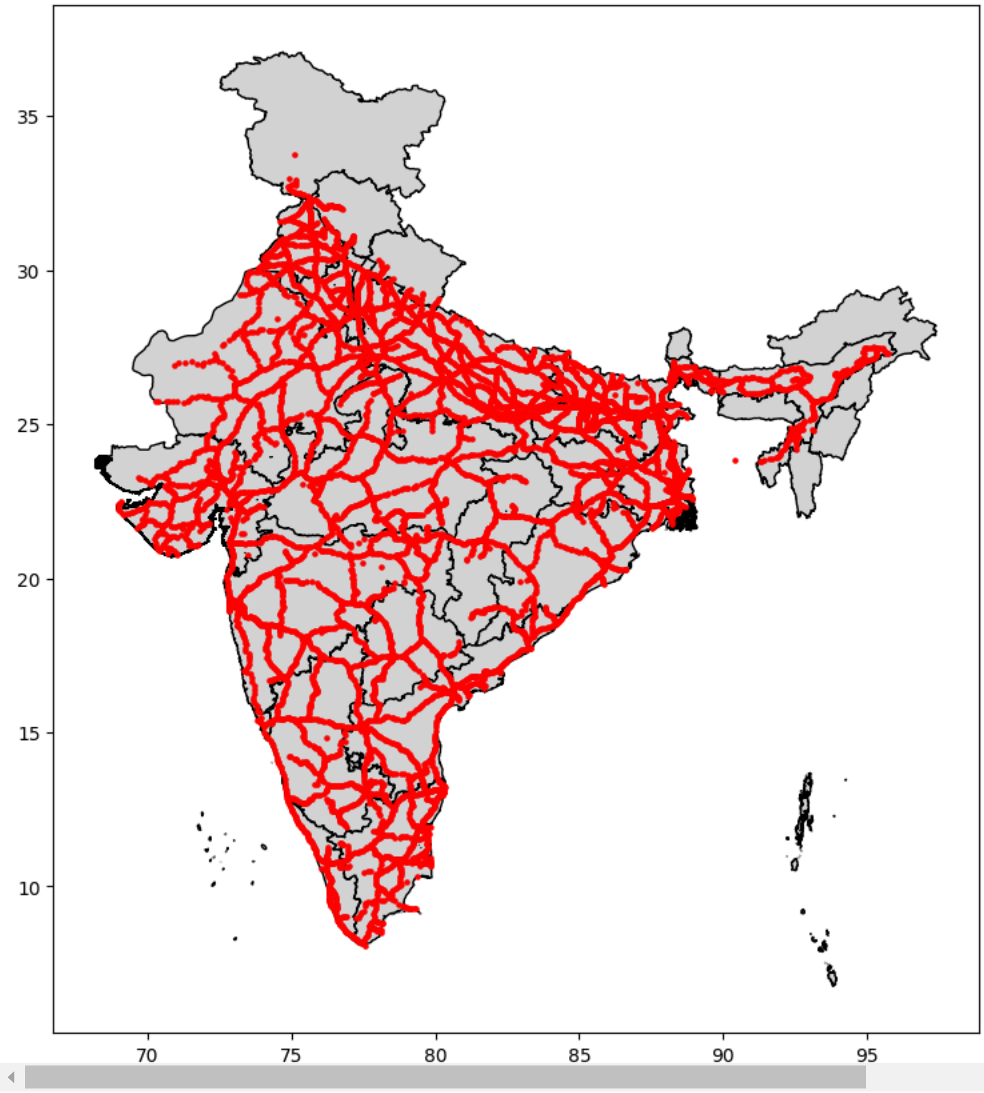
Using matplotlib to plot state and stations json data

```
import matplotlib.pyplot as plt
fig, ax = plt.subplots()
states_ind.plot(ax=ax, color='lightgray', edgecolor='black')
stations_gdf.plot(ax=ax, color='red', markersize=5)
plt.show()
```



```
import geopandas as gpd
import matplotlib.pyplot as plt

# Step 1: Remove rows with None geometries
stations_gdf = stations_gdf[stations_gdf['geometry'].notnull()]

# Step 2: Check for invalid geometries (if any)
invalid_geometries = stations_gdf[~stations_gdf.is_valid]
print("Invalid Geometries before fixing:")
print(invalid_geometries)

# Step 3: Fix invalid geometries by buffering (this can help with self-intersections)
stations_gdf['geometry'] = stations_gdf['geometry'].apply(lambda x: x.buffer(0) if not x.is_valid else x)

# Step 4: Recheck invalid geometries after fixing
invalid_geometries_after_fix = stations_gdf[~stations_gdf.is_valid]
print("Invalid Geometries after fixing:")
print(invalid_geometries_after_fix)

# Step 5: Remove any empty geometries again after fixing
stations_gdf = stations_gdf[~stations_gdf['geometry'].is_empty]

# Step 6: Plot the data
fig, ax = plt.subplots(figsize=(10, 10))

# Plot the states as a base map
states_ind.plot(ax=ax, color='lightgray', edgecolor='black')

# Plot the stations as red points with a size of 5
stations_gdf.plot(ax=ax, color='red', markersize=5)

# Show the plot
plt.show()
```

```
Invalid Geometries before fixing:
Empty GeoDataFrame
Columns: [geometry, state, code, name, zone, address]
Index: []
Invalid Geometries after fixing:
Empty GeoDataFrame
Columns: [geometry, state, code, name, zone, address]
Index: []
```



```
df_stations = df_stations[['code','name','zone','st_nm','geometry']]
df_stations.head()
```

	code	name	zone	st_nm	geometry
0	BDHL	Badhal	NWR	Rajasthan	POINT (75.45165 27.25206)
4	KHH	KICHHA	NER	Uttarakhand	POINT (79.51975 28.91343)
5	SRKN	Sherekan	NWR	Rajasthan	POINT (74.43499 29.5552)
6	BKKA	Bhukarka	NWR	Rajasthan	POINT (74.75103 29.23823)
7	NHR	Nohar	NWR	Rajasthan	POINT (74.77363 29.19256)

Checking CRS of both geodataframes

```
print(stations_gdf.crs)  # Check CRS of stations_gdf
print(states_ind.crs)    # Check CRS of states_ind

# Align CRS if different
if stations_gdf.crs != states_ind.crs:
    states_ind = states_ind.to_crs(stations_gdf.crs)
```

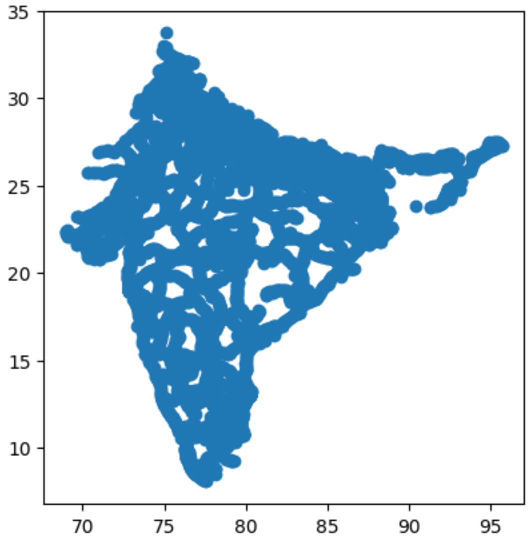
```
EPSG:4326
EPSG:4326
```

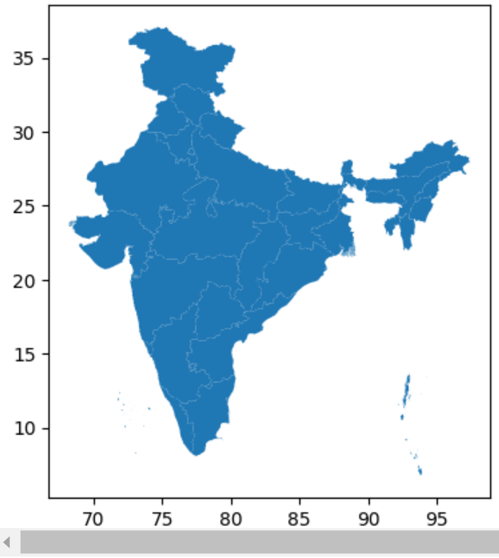
```
print(stations_gdf.is_valid.all())  # Check if geometries are valid
print(states_ind.is_valid.all())
```

```
False
False
```

```
stations_gdf.plot()
states_ind.plot()
```

```
<Axes: >
```





```
# Check validity of geometries
print("Invalid geometries in stations_gdf:", stations_gdf[~stations_gdf.is_valid])
print("Invalid geometries in states_ind:", states_ind[~states_ind.is_valid])
```

```
Invalid geometries in stations_gdf:      geometry state           code           name  zone address
1        None  None        XX-BECE        XX-BECE  None    None
2        None  None        XX-BSPY        XX-BSPY  None    None
3        None  None        YY-BPLC        YY-BPLC  None    None
25       None  None           BJUP           BJUP  None    None
29       None  None           CIKA           CIKA  None    None
...       ...   ...            ...            ...   ...     ...
8007     None  None           LCAB           LCAB  None    None
8025     None  None           BELG           BELG  None    None
8137     None  None           KANL           KANL  None    None
8276     None  None           YADA           YADA  None    None
8643     None  None  YAKUT PUR(YKA  YAKUT PUR(YKA  None    None

[293 rows x 6 columns]
Invalid geometries in states_ind:          st_nm                                           geometry
28  Tamil Nadu  MULTIPOLYGON (((78.19188 8.7273, 78.18996 8.72...
```

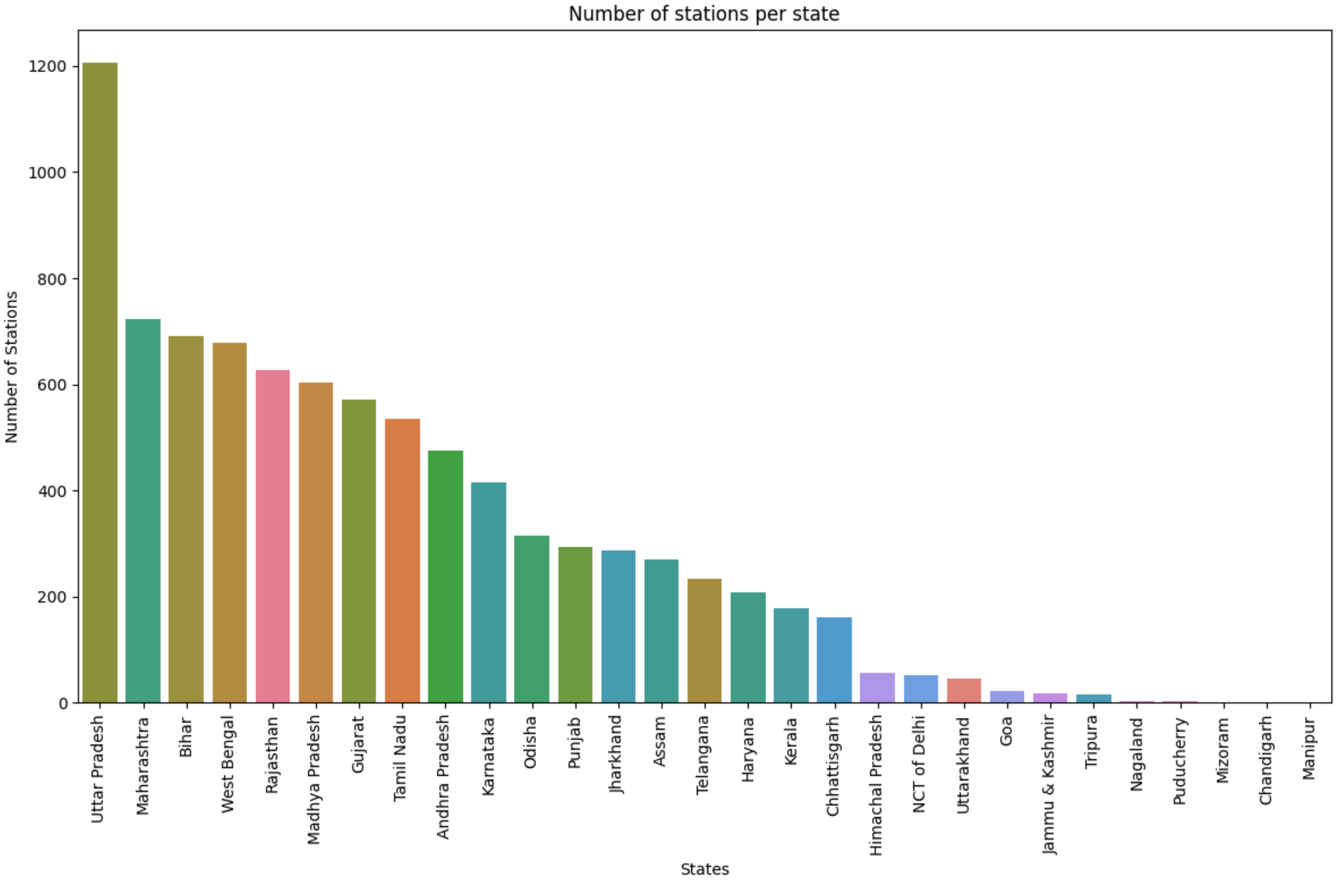
EXPLORATORY DATA ANALYSIS

How many stations are there in each state?

```
station_count = df_stations['st_nm'].value_counts()
station_count.head()
```

st_nm	count
Uttar Pradesh	1207
Maharashtra	724
Bihar	691
West Bengal	678
Rajasthan	626

```
plt.figure(figsize=(12, 8))
sns.countplot(data=df_stations, x='st_nm', hue='st_nm', order=station_count.index)
plt.xlabel('States')
plt.ylabel('Number of Stations')
plt.title('Number of stations per state')
plt.xticks(rotation=90)
plt.tight_layout()
plt.show()
```



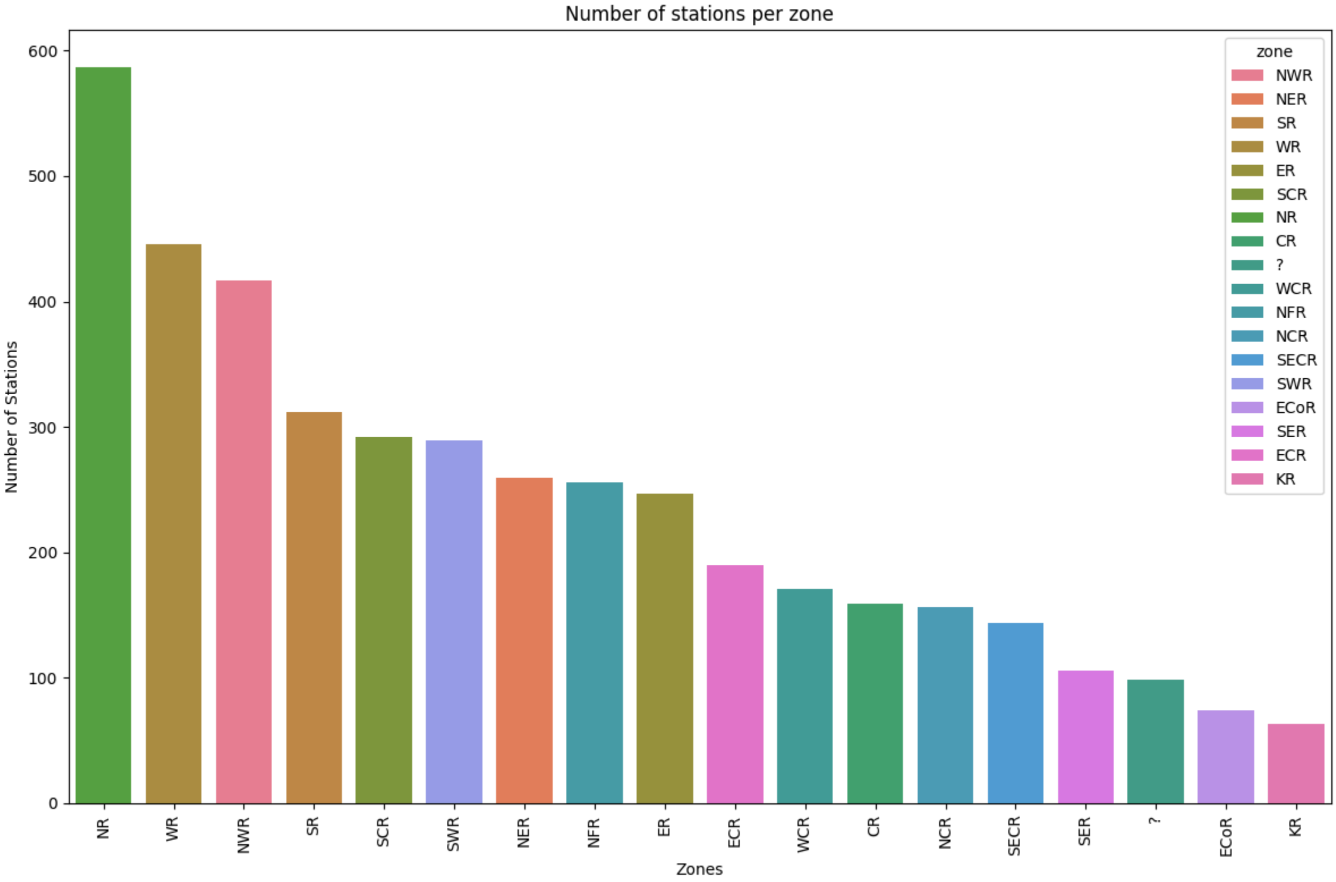
Remarks : Uttar Pradesh has the most number of stations in India

How many stations are there in each railway zone?

```
station_count = df_stations['zone'].value_counts()
station_count
```

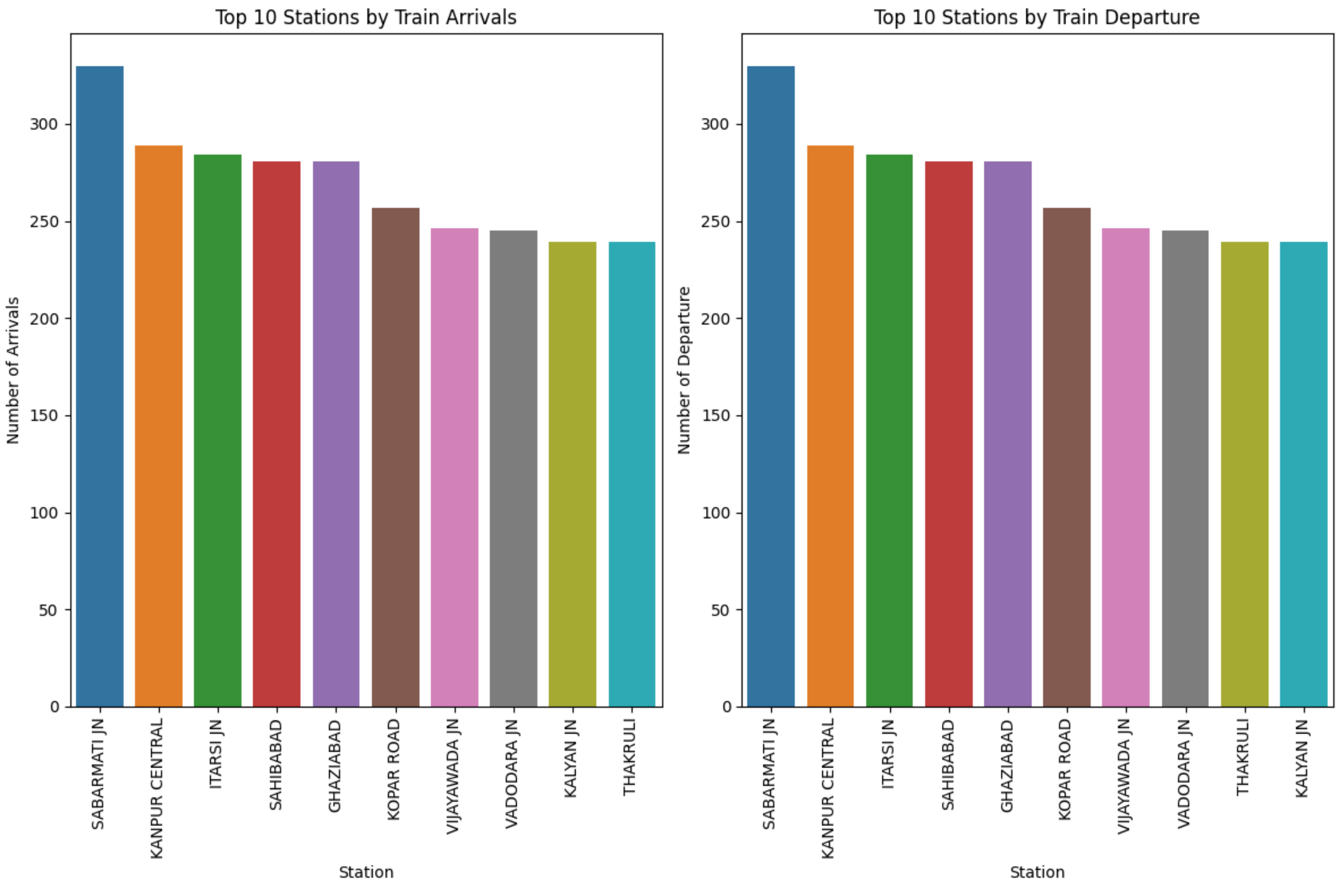
```
        count
zone
  NR      587
  WR      446
 NWR      417
  SR      312
 SCR      292
 SWR      289
 NER      259
 NFR      256
  ER      247
 ECR      190
 WCR      171
  CR      159
 NCR      156
SECR      144
 SER      106
   ?       98
ECoR       74
  KR       63

dtype: int64
```

```
plt.figure(figsize=(12, 8))
sns.countplot(data=df_stations, x='zone', hue='zone', order=station_count.index)
plt.xlabel('Zones')
plt.ylabel('Number of Stations')
plt.title('Number of stations per zone')
plt.xticks(rotation=90)
plt.tight_layout()
plt.show()
```



Which stations have the highest number of train arrivals and departures?

```
not_null_arrivals = schedules[schedules['arrival'] != 'None']
not_null_departure = schedules[schedules['departure'] != 'None']


station_arrivals = not_null_arrivals.groupby('station_name').size().reset_index(name='arrivals_count')
station_departures = not_null_departure.groupby('station_name').size().reset_index(name='departures_count')


arr = station_arrivals.sort_values(by='arrivals_count', ascending = False).head(10)
dep = station_departures.sort_values(by='departures_count', ascending = False).head(10)


plt.figure(figsize=(12, 8))

plt.subplot(1, 2, 1)
sns.barplot(data=arr, x='station_name', y = 'arrivals_count',hue='station_name')
plt.xlabel('Station')
plt.ylabel('Number of Arrivals')
plt.title('Top 10 Stations by Train Arrivals')
plt.xticks(rotation = 90)

plt.subplot(1, 2, 2)
sns.barplot(data=dep, x='station_name', y = 'departures_count',hue='station_name')
plt.xlabel('Station')
plt.ylabel('Number of Departure')
plt.title('Top 10 Stations by Train Departure')
plt.xticks(rotation = 90)

plt.tight_layout()
plt.show()
```



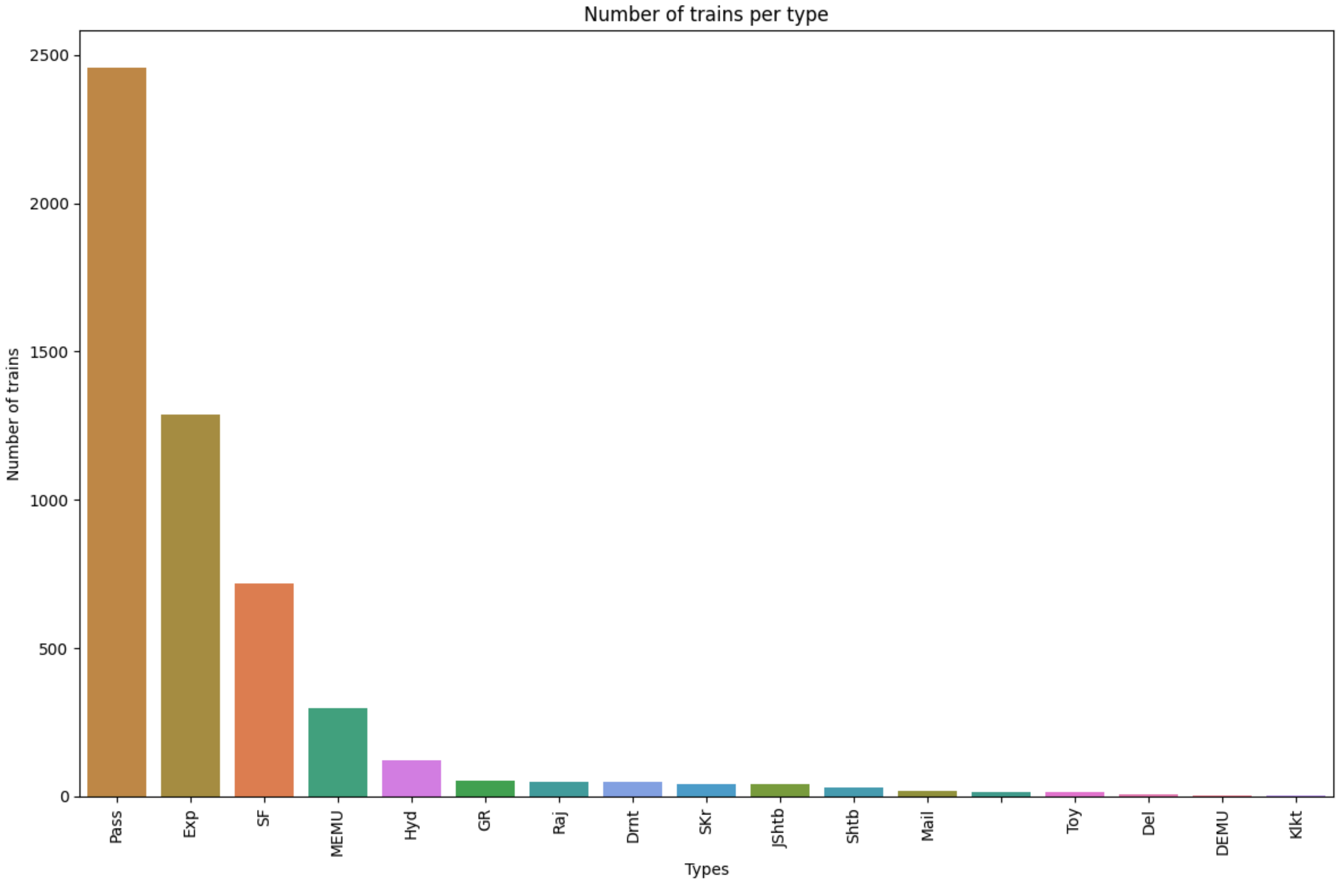
How many trains offer each class of service (e.g., first class, second AC, sleeper, etc.)?

```
classes = ['chair_car','sleeper','third_ac','second_ac','first_class','first_ac']


for i in classes:
    print(f'Number of trains having {i} : {trains_gdf[trains_gdf[i] == 1].shape[0]}')
```

```
Number of trains having chair_car : 403
Number of trains having sleeper : 1759
Number of trains having third_ac : 1650
Number of trains having second_ac : 1417
Number of trains having first_class : 167
Number of trains having first_ac : 439
```

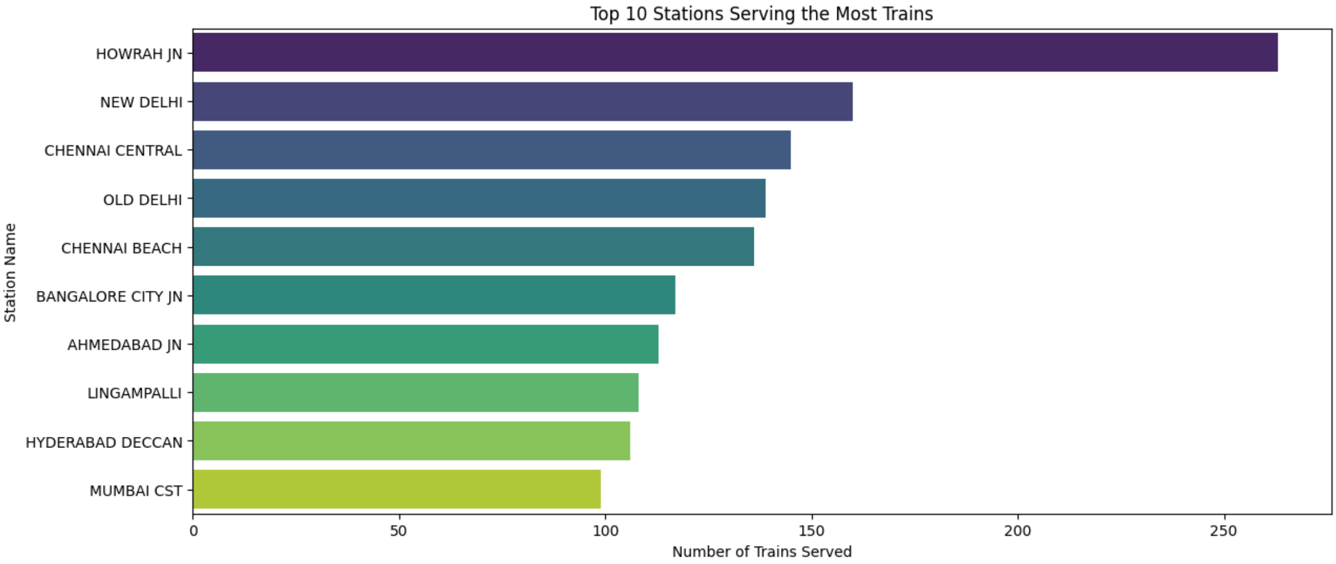
What are the different types of trains available?

```
types = trains_gdf['type'].value_counts()


plt.figure(figsize=(12, 8))
sns.countplot(data=trains_gdf, x='type', hue='type', order=types.index)
plt.xlabel('Types')
plt.ylabel('Number of trains')
plt.title('Number of trains per type')
plt.xticks(rotation=90)
plt.tight_layout()
plt.show()
```



Which stations serve the most trains?

```
departures = trains_gdf['from_station_name'].value_counts().reset_index(name='departures_count')
departures.rename(columns={'from_station_name': 'station_name'}, inplace=True)

arrivals = trains_gdf['to_station_name'].value_counts().reset_index(name='arrivals_count')
arrivals.rename(columns={'to_station_name': 'station_name'}, inplace=True)

station_counts = pd.merge(departures, arrivals, on='station_name',how='outer').fillna(0)

station_counts['total_trains'] = station_counts['departures_count'] + station_counts['arrivals_count']

top_stations = station_counts.sort_values(by='total_trains', ascending=False)

# Plot the top 10 stations serving the most trains
top_10_stations = top_stations.head(10)

plt.figure(figsize=(14, 6))
sns.barplot(data=top_10_stations, x='total_trains', y='station_name',hue = 'station_name',palette='viridis')
plt.title('Top 10 Stations Serving the Most Trains')
plt.xlabel('Number of Trains Served')
plt.ylabel('Station Name')
plt.show()
```

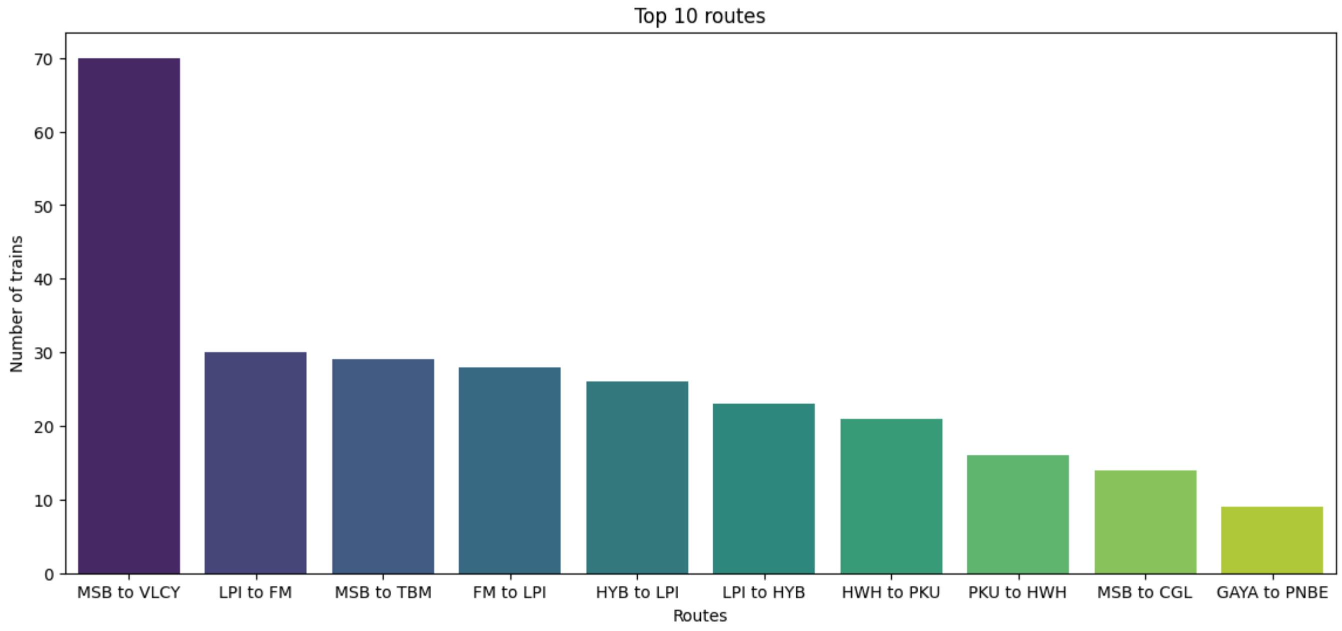


What are the most common routes (from_station_code to to_station_code)?

```
routes = trains_gdf.groupby(['from_station_code','to_station_code']).size().reset_index(name='count')
most_common_routes = routes.sort_values(by='count', ascending=False)
most_common_routes.head(10)
```

	from_station_code	to_station_code	count
2225	MSB	VLCY	70
1965	LPI	FM	30
2222	MSB	TBM	29
1135	FM	LPI	28
1463	HYB	LPI	26
1966	LPI	HYB	23
1433	HWH	PKU	21
2569	PKU	HWH	16
2219	MSB	CGL	14
1174	GAYA	PNBE	9

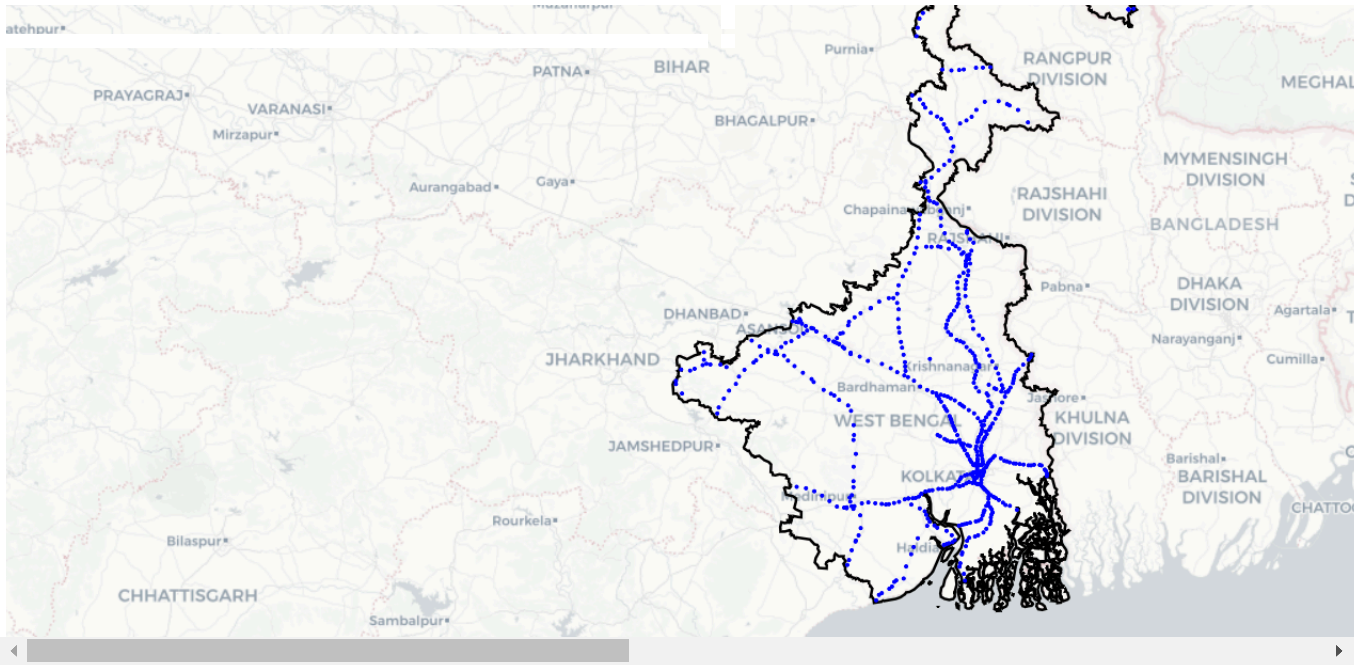
```
most_common_routes['route'] = most_common_routes['from_station_code'] + ' to ' + most_common_routes['to_station_code']
most_common_routes = most_common_routes.head(10)


plt.figure(figsize=(14, 6))
sns.barplot(data=most_common_routes, x='route', y = 'count',hue = 'route',palette='viridis')
plt.title('Top 10 routes')
plt.xlabel('Routes')
plt.ylabel('Number of trains')
plt.show()
```



GEO VISUALISATION

```
import plotly.graph_objects as go


def process_polygon(boundaries_gdf):
    boundary_lines = []

    for idx, row in boundaries_gdf.iterrows():
        geom = row['geometry']
        if geom.geom_type == 'Polygon':
            boundary_lines.append(go.Scattermapbox(
            mode="lines",
            lon=[coord[0] for coord in geom.exterior.coords],
            lat=[coord[1] for coord in geom.exterior.coords],
            name='ST_NM',
            showlegend=False,
            line=dict(color='black'),
        ))
        if geom.geom_type == 'MultiPolygon':
            for poly in geom.geoms:
                boundary_lines.append(go.Scattermapbox(
                mode="lines",
                lon=[coord[0] for coord in poly.exterior.coords],
                lat=[coord[1] for coord in poly.exterior.coords],
                name='ST_NM',
                showlegend=False,
                line=dict(color='black'),

                ))
    return boundary_lines


def process_station_points(stations_gdf):
    station_points = go.Scattermapbox(
        mode="markers",
        lon=stations_gdf.geometry.x,
        lat=stations_gdf.geometry.y,
        marker=dict(size=4, color='blue'),
        text=stations_gdf['name'],
        name='name',
        showlegend=False
    )

    return station_points


def plot_stations(stations_gdf, state_name=None):

    clat = 24
    clon = 80
    zoom = 4
    title = 'India'

    boundaries_gdf = states_ind

    if state_name:
        all_states = list(states_ind['st_nm'].unique())

        if state_name in all_states:
            boundaries_gdf = states_ind[states_ind['st_nm'] == state_name]
            stations_gdf = stations_gdf[stations_gdf['st_nm'] == state_name

            clat = stations_gdf.geometry.y.mean()
            clon = stations_gdf.geometry.x.mean()
            zoom = 6
            title = state_name
        else:
            return '`state_name` not matching with the records.'

    boundary_lines = process_polygon(boundaries_gdf)
    station_points = process_station_points(stations_gdf)

    fig = go.Figure(boundary_lines + [station_points])

    fig.update_layout(
        mapbox_style="carto-positron",
        mapbox=dict(
            center=dict(lat=clat, lon=clon),
            zoom=6
        ),
        title=title,
        margin={"r":0,"t":40,"l":0,"b":0},
    )

    fig.show()

plot stations(df stations,'West Bengal')
```

West Bengal



Some Observations

- Uttar Pradesh has the most number of stations
- Most stations are served by Northen Railway
- Passenger train type is the most common train types.
- Howrah Junction serves most trains based on Arrival and departure
- MSB is the most common departure station
- VLCY is the most common arrival station