combination of data sources - exploratory

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0.1 ENVM1400 - I & A - Volta group - DGRE

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[1]:
```python
import glob
import os

# data/plot management
import pandas as pd
import matplotlib
import matplotlib.pyplot as plt
import numpy as np

import warnings

# plotting/mapmaknig
import geopandas as gpd
from geospatial_functions import get_background_map
import rasterio
from rasterio.plot import show as rioshow
import folium

warnings.simplefilter('ignore')
```

All data from the different sources is combined in this notebook

[2]:
```python
path = os.getcwd()
home_path = os.path.dirname(path)
main_folder = os.path.dirname(home_path)

gis_folder = f'{main_folder}\\QGIS project'
```

Load in gis data

[3]:
```python
country_outline = gpd.read_file(f"{gis_folder}\\country_outline_32630.gpkg")
volta_outline = gpd.read_file(f"{gis_folder}\\volta_watershed_vector_32630.
↪gpkg",crs="epsg:32630")
main_rivers = gpd.read_file(f"{gis_folder}\\main_rivers_volta.gpkg",crs="epsg:
↪32630")
```

```python
country_outline = country_outline.set_geometry(country_outline.geometry.
 ↪to_crs('EPSG:4326'))
volta_outline = volta_outline.set_geometry(volta_outline.geometry.to_crs('EPSG:
 ↪4326'))
main_rivers = main_rivers.set_geometry(main_rivers.geometry.to_crs('EPSG:4326'))
```

glob allows the reading files based on regular expressions, i.e. all geojson files with **.geojson*

[4]:
```python
glob.glob("*.geojson")
```

[4]:
```
['discharge_data_client.geojson',
 'discharge_data_reasearch_gate.geojson',
 'precipitation_data_client.geojson']
```

[5]:
```python
gdf_precip = gpd.read_file('precipitation_data_client.geojson',crs="EPSG:4326")
gdf_discharge_research_gate = gpd.read_file('discharge_data_reasearch_gate.
 ↪geojson',crs="EPSG:4326")
gdf_discharge_client = gpd.read_file('discharge_data_client.geojson',crs="EPSG:
 ↪4326")
gdf_discharge_client['name'] = gdf_discharge_client.apply(lambda x: x['name'].
 ↪split(",")[-1][:-4].strip().lower(),axis=1)
```

[6]:
```python
gdf_discharge_client
```

[6]:

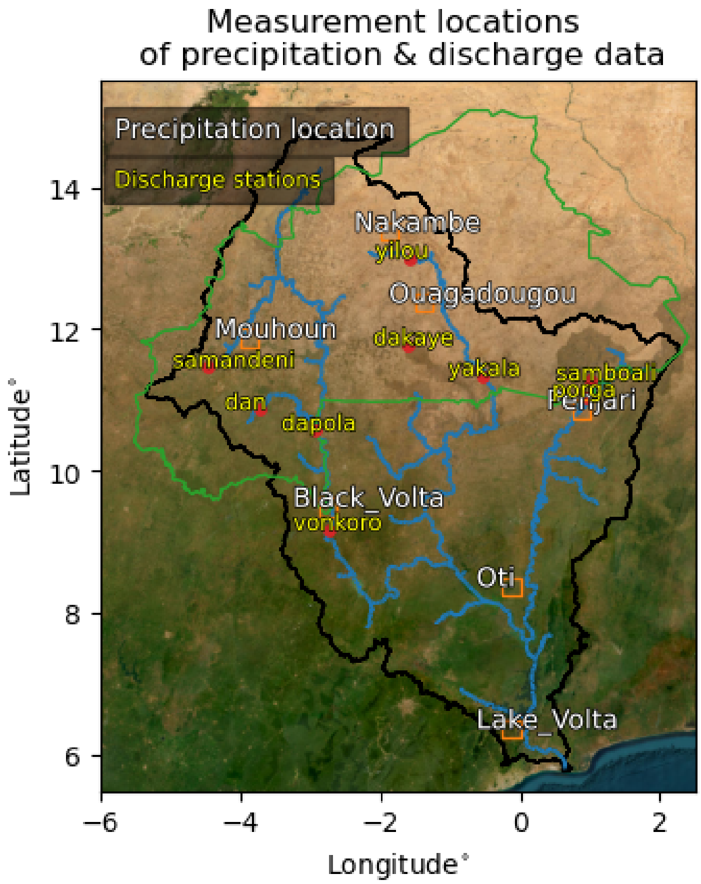
	name	lat	lon	geometry
0	vonkoro	9.171205	-2.744841	POINT (-2.74484 9.17121)
1	dan	10.867876	-3.722479	POINT (-3.72248 10.86788)
2	samandeni	11.458715	-4.469477	POINT (-4.46948 11.45872)
3	dapola	10.572862	-2.914135	POINT (-2.91413 10.57286)
4	yakala	11.344608	-0.528965	POINT (-0.52897 11.34461)
5	yilou	12.999710	-1.570603	POINT (-1.57060 12.99971)
6	dakaye	11.777456	-1.600156	POINT (-1.60016 11.77746)
7	porga	11.045433	0.959914	POINT (0.95991 11.04543)
8	samboali	11.279537	1.015889	POINT (1.01589 11.27954)

This data loaded in can be visualised using geopandas

[7]:
```python
# quick way to get the bounds
fig, ax = plt.subplots()

#adding features
volta_outline.plot(ax=ax,edgecolor="k", facecolor='none')
main_rivers.plot(ax=ax, color="C0",zorder=1)
country_outline.plot(ax=ax, facecolor="none", edgecolor="C2",zorder=6)

# get the bounds to add background
```

```python
bounds_stations = (ax.get_xlim()[0], ax.get_ylim()[0], ax.get_xlim()[1], ax.get_ylim()[1])

# add stations
gdf_discharge_client.plot(ax=ax,color="C3",markersize=15,zorder=10)
with rasterio.open(get_background_map("stations", bounds_stations)) as r:
    rioshow(r, ax=ax)

gdf_precip.plot(ax=ax, facecolor="none",edgecolor="C1",zorder=10)

# add labels
mid_points = gdf_precip.geometry.centroid
for index, name in enumerate(gdf_precip.name):
    ax.annotate(f"{name}" ,
                (mid_points.iloc[index].x-0.5,mid_points.iloc[index].y),zorder=10, color="w",
                 path_effects=[matplotlib.patheffects.withStroke(linewidth=1, foreground="k")])

for index, name in enumerate(gdf_discharge_client.name):
    ax.annotate(f"{name}" ,
                (gdf_discharge_client.iloc[index].geometry.x-0.5,
                 gdf_discharge_client.iloc[index].geometry.y),zorder=10, color="yellow",
                 path_effects=[matplotlib.patheffects.withStroke(linewidth=1, foreground="k")],
                 fontsize="small")

# legend
legend1 = ax.annotate(f"Discharge stations" ,
                (-5.8, 7*2),zorder=10, color="yellow",
                 path_effects=[matplotlib.patheffects.withStroke(linewidth=1, foreground="k")],
                 fontsize="small")

legend2 = ax.annotate(f"Precipitation location" ,
            (-5.8, 14.69),zorder=10, color="w",
             path_effects=[matplotlib.patheffects.withStroke(linewidth=1, foreground="k")])

legend1.set_bbox(dict(facecolor='black', alpha=0.5))
legend2.set_bbox(dict(facecolor='black', alpha=0.5))
# set appearance
ax.set_title("Measurement locations \n of precipitation & discharge data")
ax.set_xlabel("Longitude$^{\circ}$");
ax.set_ylabel("Latitude$^{\circ}$");
```

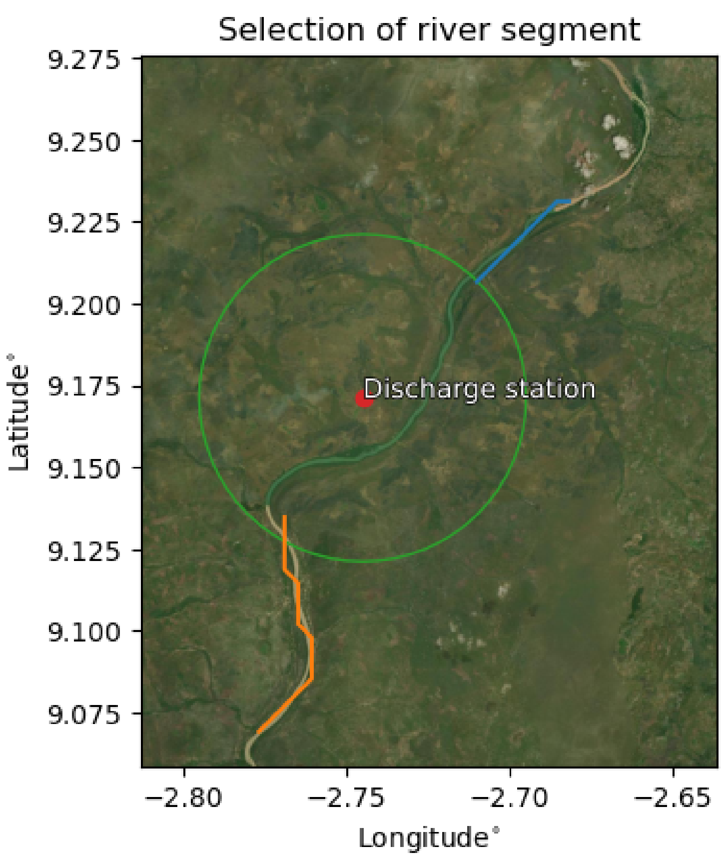
```
ax.set_ylim((5.5,15.5))
ax.set_xlim((-6,2.5));

fig.savefig('locations.png', transparent=True,pad_inches=0)
```



per discharge station we want to select a river segment, this is then shown below using geopandas

[8]:
```
i=0
point_discharge = gdf_discharge_client.iloc[i].geometry.buffer(0.05)
selected_segement =  main_rivers[main_rivers.crosses(point_discharge)]
buffers = gpd.GeoDataFrame(index=[0],geometry=[point_discharge],crs="epsg:4326")
fig, ax = plt.subplots(1)
try:
    selected_segement.iloc[[0]].plot(ax=ax)
    selected_segement.iloc[[1]].plot(ax=ax,color="C1")
    gdf_discharge_client.iloc[[i]].plot(ax=ax,color="C3")
    buffers.plot(ax=ax,facecolor="none",edgecolor="C2")
    ax.annotate("Discharge station",(gdf_discharge_client.iloc[[i]].geometry.x,
```

```
                                     gdf_discharge_client.iloc[[i]].geometry.y),
               zorder=10, color="w",
               path_effects=[matplotlib.patheffects.withStroke(linewidth=1,␣
 ↪foreground="k")])

    bounds_stations = (ax.get_xlim()[0], ax.get_ylim()[0], ax.get_xlim()[1], ax.
 ↪get_ylim()[1])
    with rasterio.open(get_background_map(f"river_selction_{i}",␣
 ↪bounds_stations)) as r:
        rioshow(r, ax=ax)


    ax.set_xlabel("Longitude$^{\circ}$");
    ax.set_ylabel("Latitude$^{\circ}$");
    ax.set_title("Selection of river segment")
except IndexError:
    print("no segement found")

selected_segement
fig.savefig('selection_of_river.png', transparent=True)
```



[9]:
```python
point_discharge = gdf_discharge_client.iloc[i].geometry.buffer(0.05)
selected_segement =  main_rivers[main_rivers.crosses(point_discharge)]
selected_location = main_rivers.loc[selected_segement.index[0],:]
selected_location.head()
```

[9]:
```
HYRIV_ID      10664588
NEXT_DOWN     10665503
MAIN_RIV      10821582
LENGTH_KM         4.36
DIST_DN_KM       870.4
Name: 984, dtype: object
```

From the selected river segment location we can get the upland flow accumulation area from hydrosheds

[10]:
```python
area_upstream_black_volta_border = selected_location.UPLAND_SKM
```

0.2 load discharge & precipitation data from analysis

precipitation:

[11]:
```python
Rainfall_BF_msum = pd.read_excel("Monthly_sum_rainfall.xlsx",index_col=0)
Rainfall_BF_msum.sum()
```

[11]:
```
Ouagadougou    31142.531074
Nakambe        26583.642558
Black_Volta    42549.332879
Mouhoun        35958.471630
Lake_Volta     53443.687723
Oti            52192.628350
Penjari        41049.957017
dtype: float64
```

discharge:

[12]:
```python
names = ['Black volta, vonkoro',
         'Bougouriba, dan',
         'Mou houn, black volta, samandeni',
         'Mou houn, black volta,dapola',
         'Nakanbe, white volta, yakala',
         'Nakanbe, white volta, yilou',
         'Nazinon, red volta, dakaye',
         'Pendjari, porga',
         'Singou, samboali']
```

[13]:
```python
df_discharge_per_location_lst = []
for name in names:
```

```
    df_discharge = pd.read_excel(f"{home_path}\\Combining data\\{name}.
↪xlsx",index_col=0)
    df_discharge_per_location_lst.append(df_discharge)
```

1 specific for black volta to start

[14]:
```
discharge_black_volta = df_discharge_per_location_lst[0].rename(columns={"black␣
↪volta, vonkoro":"Q"})
```

[15]:
```
months_with_data = discharge_black_volta.apply(lambda x: f'{x.name.month}-{x.
↪name.year}', axis=1).unique()
```

not all months include data, filter only the months with data

[16]:
```
months_with_data
```

[16]:
```
array(['1-1979', '2-1979', '3-1979', '4-1979', '5-1979', '6-1979',
       '7-1979', '8-1979', '9-1979', '10-1979', '11-1979', '12-1979',
       '1-1982', '2-1982', '3-1982', '4-1982', '5-1982', '6-1982',
       '7-1982', '8-1982', '9-1982', '10-1982', '11-1982', '12-1982',
       '1-1993', '2-1993', '3-1993', '4-1993', '5-1993', '6-1993',
       '7-1993', '8-1993', '9-1993', '10-1993', '11-1993', '12-1993'],
      dtype=object)
```

[17]:
```
discharge_black_volta_msum = discharge_black_volta.resample('M').sum()
discharge_black_volta_msum['timestamp'] = discharge_black_volta_msum.
↪apply(lambda x: x.name, axis=1)
discharge_black_volta_msum.index = \
                                discharge_black_volta_msum.apply(lambda x: f'{x.
↪name.month}-{x.name.year}', axis=1)
discharge_black_volta_msum_sorted = discharge_black_volta_msum.
↪loc[months_with_data]
discharge_black_volta_msum_sorted.index =␣
↪discharge_black_volta_msum_sorted['timestamp']
discharge_black_volta_msum_sorted.drop(columns="timestamp",inplace=True)
discharge_black_volta_msum_sorted.head(5)
```

[17]:
```
                 Q
timestamp
1979-01-31   253.0
1979-02-28    77.0
1979-03-31    18.0
1979-04-30    18.0
1979-05-31  1063.0
```

Q in m^3/s -> sum these is total m^3/s in one month -> m^3/month -> * 3600 * 24 * 30

```
[18]: discharge_black_volta_msum_sorted.Q = \
discharge_black_volta_msum_sorted.apply(lambda x: x.Q * x.name.days_in_month *␣
↪24 * 3600 , axis=1) #m^3/month
```

add column with month index for later

```
[19]: discharge_black_volta_msum_sorted["month"] = discharge_black_volta_msum_sorted.
↪apply(lambda x: x.name.month, axis=1)
```

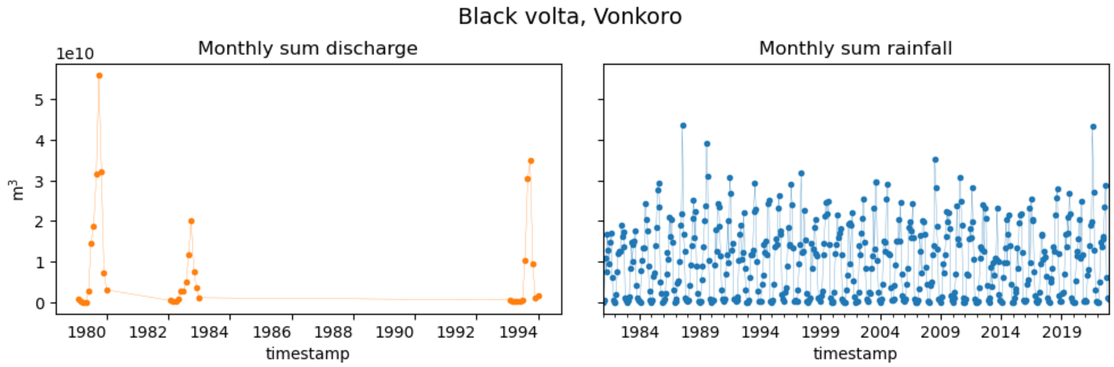
```
[20]: rainfall_black_volta = Rainfall_BF_msum[["Black_Volta"]].
↪rename(columns={"Black_Volta":"P"})
```

convert precipitation to m^3/month

```
[21]: black_volta_basin_area = selected_location.UPLAND_SKM * 10**6  # km^2 -> m^2
rainfall_black_volta.P = rainfall_black_volta.P * black_volta_basin_area / 1000␣
↪# mm/month * m^2 ->/1000 =  m^3/month
```

plot (for presentation)

```
[22]: fig, ax = plt.subplots(1,2,sharey=True,figsize=(10,3))
fig.tight_layout(h_pad=1.6)
fig.suptitle("Black volta, Vonkoro",y=1.10,fontsize=14)
discharge_black_volta_msum_sorted.Q.plot(marker=".",lw=0.2,color="C1",ax=ax[0])
ax[0].set_title("Monthly sum discharge")
ax[0].set_ylabel("m$^3$")
labels_0 = ax[0].get_xticklabels()
ax[0].set_xticklabels(labels_0,rotation=0);

rainfall_black_volta.index.name = 'timestamp'
rainfall_black_volta.plot(lw=0.2, marker=".", ax=ax[1])
ax[1].set_title("Monthly sum rainfall")
ax[1].set_ylabel("m$^3$")
ax[1].get_legend().remove()

### in case of bargraph fix xaxis
# ticks = ax.get_xticks()
# ax.set_xticks(np.linspace(min(ticks),max(ticks),num=10,dtype=int))
# labels = ax.get_xticklabels()
# [labels[i].set_text(labels[i].get_text()[:4]) for i in range(len(labels))]
# ax.set_xticklabels(labels,rotation=0);
# ax.get_xticks()
```



1.1 Evaporation

Ensure the Pyeto package is present in your lib file under anaconda

[23]:
```
from pyeto import thornthwaite, monthly_mean_daylight_hours, deg2rad
```

[24]:
```
lat = deg2rad(gdf_discharge_client[gdf_discharge_client['name']=="vonkoro"].
    ↪iloc[0].geometry.y)
```

Read file with temperature

[25]:
```
df_temperature = pd.
    ↪read_excel(f"{home_path}\\Evaporation\\daily_Near-Surface-Air-Temperature.
    ↪xlsx",
                               index_col=0,parse_dates=True)
df_temperature.rename(columns={0:"Temperature"},inplace=True)
# df_temperature_msum = df_temperature.resample('M').mean()
```

[26]:
```
# df_temperature
```

[27]:
```
df_temperature_msum = df_temperature.resample('M').mean()
```

[28]:
```
df_temperature_msum
```

[28]:

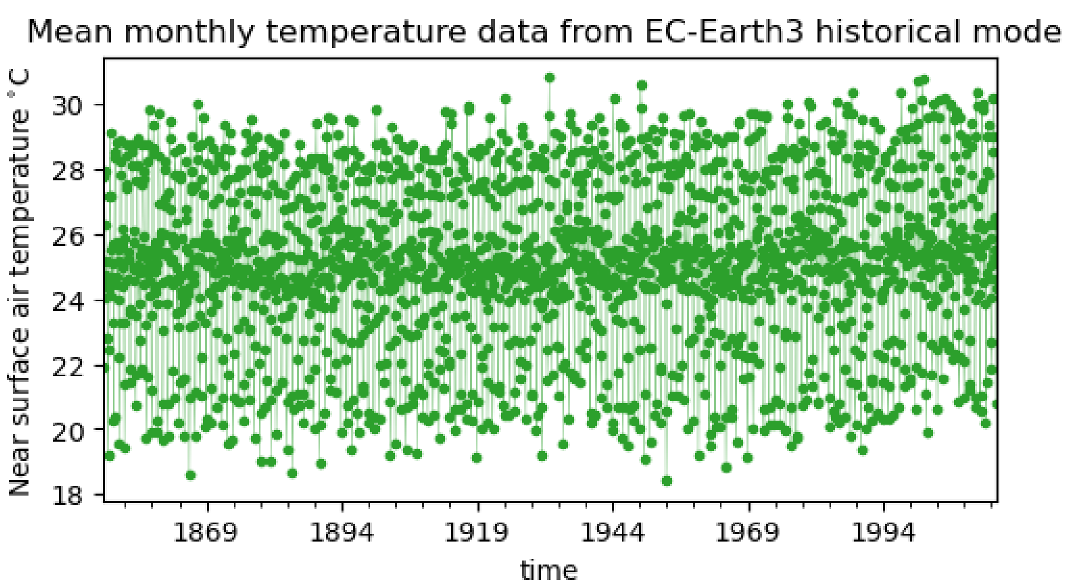
	Temperature
time	
1850-01-31	21.941219
1850-02-28	25.177965
1850-03-31	27.767814
1850-04-30	27.923712
1850-05-31	26.293062
…	…
2014-08-31	25.295572
2014-09-30	25.531935

```
2014-10-31    26.489012
2014-11-30    24.366937
2014-12-31    20.803242

[1980 rows x 1 columns]
```

[29]:
```python
gdf_discharge_client['name']
```

[29]:
```
0      vonkoro
1          dan
2    samandeni
3       dapola
4       yakala
5        yilou
6       dakaye
7        porga
8     samboali
Name: name, dtype: object
```

[30]:
```python
fig, ax = plt.subplots(figsize=(6,3))
df_temperature_msum.plot(marker=".", lw=0.2,ax=ax,color="C2")
ax.set_ylabel("Near surface air temperature $^{\circ}$C")
ax.set_title("Mean monthly temperature data from EC-Earth3 historical model")
ax.get_legend().remove()
```



[31]:
```python
df_temperature_msum
```

[31]:
```
            Temperature
time
1850-01-31    21.941219
1850-02-28    25.177965
1850-03-31    27.767814
1850-04-30    27.923712
1850-05-31    26.293062
…                   …
2014-08-31    25.295572
2014-09-30    25.531935
2014-10-31    26.489012
2014-11-30    24.366937
2014-12-31    20.803242

[1980 rows x 1 columns]
```

mean between 6° W and 6°E and between 5°N and 15°N

[32]:
```
mmdlh = monthly_mean_daylight_hours(lat, 2022)
```

[33]:
```
month = np.arange(1,13,1)
df_light_hrs = pd.
 ↪DataFrame(columns=['month',"daylight_hours"],data=list(zip(month, mmdlh)))
df_light_hrs.index = df_light_hrs.month
df_light_hrs.drop(columns="month",inplace=True)
df_light_hrs.head(3)
```

[33]:
```
       daylight_hours
month
1            11.531050
2            11.709220
3            11.950543
```

[34]:
```
years = df_temperature_msum.index.year.unique()
for year in years:
    mmdlh = monthly_mean_daylight_hours(lat, year)
    # use thornthwaite to calculate the
    evap = thornthwaite(df_temperature_msum[f'{year}'].Temperature.to_list(),␣
 ↪mmdlh, year=year)
    set_items = df_temperature_msum[f'{year}'].index
    df_temperature_msum.loc[set_items,"evap"] = evap
```

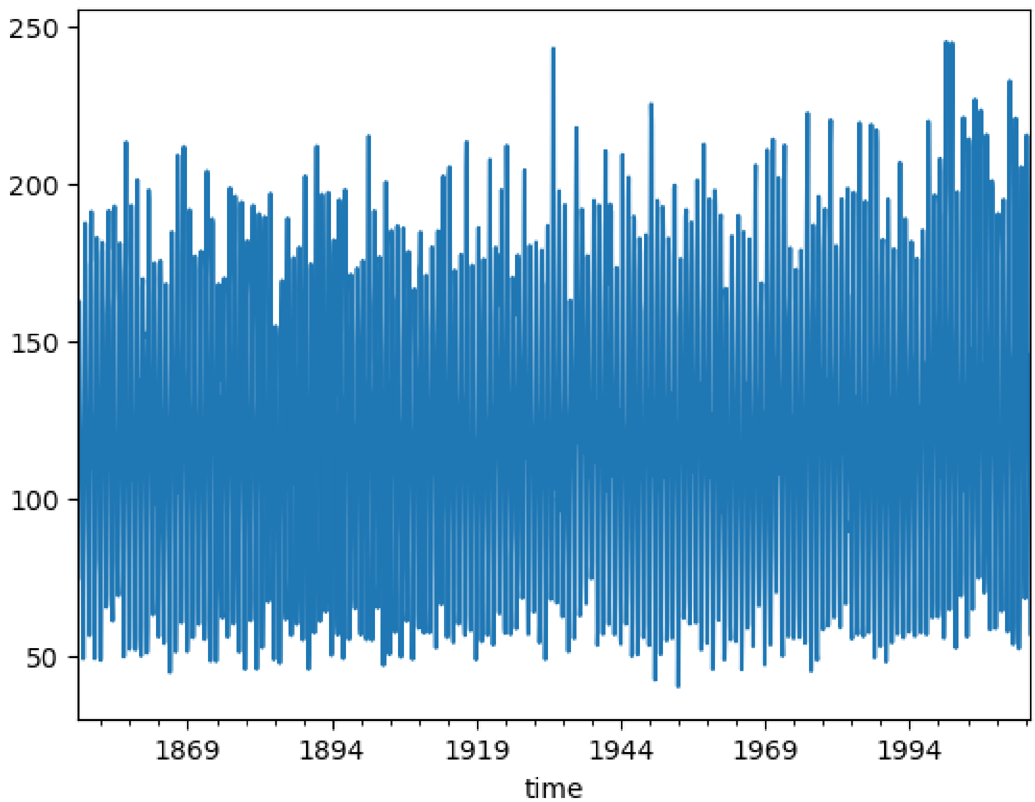
[35]:
```
df_temperature_msum.head()
```

[35]:
```
            Temperature        evap
time
1850-01-31    21.941219   74.640526
1850-02-28    25.177965  105.213675
```

```
1850-03-31    27.767814  161.412572
1850-04-30    27.923712  162.396570
1850-05-31    26.293062  141.487595
```

[36]:
```
df_temperature_msum.evap.plot()
```

[36]:
```
<AxesSubplot: xlabel='time'>
```



[37]:
```
black_volta_basin_area = selected_location.UPLAND_SKM * 10**6   # km^2 -> m^2
df_temperature_msum["E"] = df_temperature_msum.evap * black_volta_basin_area /
  ↪1000 # mm/month * m^2 ->/1000 =  m^3/month
```

2 Combine data

[38]:
```
combined_df = discharge_black_volta_msum_sorted.copy()
combined_df["P"] = rainfall_black_volta["P"]
combined_df["E"] = df_temperature_msum["E"]
combined_df["Diff"] = combined_df["P"] - combined_df["Q"] - combined_df["E"]
```

[39]:
```
combined_df.head(5)
```

[39]:

```
                        Q  month   P             E  Diff
timestamp
1979-01-31  6.776352e+08      1 NaN  6.961084e+09   NaN
1979-02-28  1.862784e+08      2 NaN  1.093395e+10   NaN
1979-03-31  4.821120e+07      3 NaN  2.136490e+10   NaN
1979-04-30  4.665600e+07      4 NaN  2.201798e+10   NaN
1979-05-31  2.847139e+09      5 NaN  2.292800e+10   NaN
```

3 Plot combined data

[40]:

```python
yearly_sum = combined_df['1982'].sum()
print(f'{yearly_sum.P - yearly_sum.Q:.2g}m^3')
```

```
5.8e+10m^3
```

[41]:

```python
yearly_sum = combined_df['1982'].sum()
print(f'{yearly_sum.P - yearly_sum.Q - yearly_sum.E:.2g}')
```

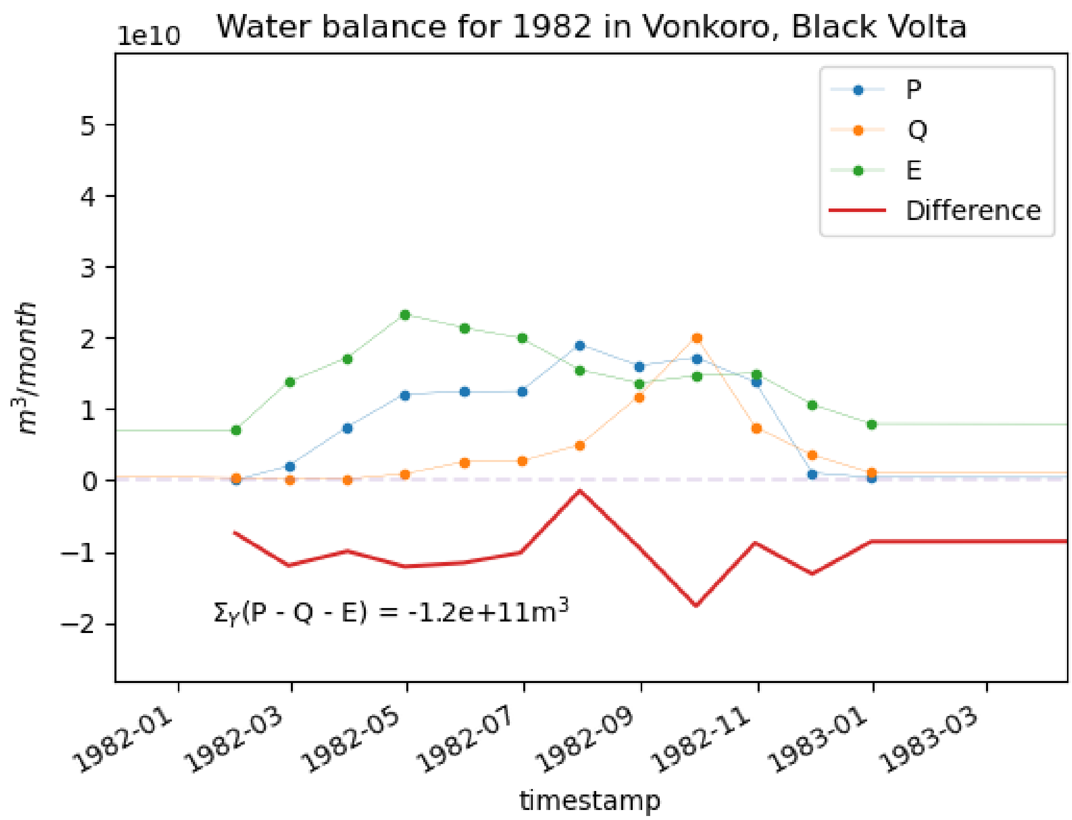
```
-1.2e+11
```

[42]:

```python
fig, ax = plt.subplots(1)
ax.set_xlabel("Date")
ax.set_ylabel("$m^3/month$")
for val in ["P","Q","E"]:
    combined_df[val].plot(marker='.',lw=0.2, ax=ax,label=val)

combined_df["Diff"].plot(ax=ax,label="Difference")
ax.set_xlim((4350,4850))
ax.get_xlim()
ax.set_title("Water balance for 1982 in Vonkoro, Black Volta")
ax.legend()
ax.axhline(0, alpha=0.2, ls="--", color="C4" )

ax.annotate(f'$\Sigma_Y$(P - Q - E) = {yearly_sum.P - yearly_sum.Q - yearly_sum.
 ↪E:.2g}m$^3$',(4400, -2e10))
ax.get_xticks()
```

[42]:

```
array([4383., 4442., 4503., 4564., 4626., 4687., 4748., 4807.])
```



optimize *factor_evap* so that yearly balance is 0

[43]:
```
from scipy.optimize import root
```

Change to tweak:

[44]:
```
year = discharge_black_volta_msum_sorted.index.year.unique()[1]
```

[45]:
```
def fobj(factor_evap, lst_dfs, year, return_df=False):
    # unpack
    discharge_black_volta_msum_sorted = lst_dfs[0]
    rainfall_black_volta = lst_dfs[1]
    df_temperature_msum = lst_dfs[2]
    # combine
    combined_df_fit = discharge_black_volta_msum_sorted.copy()
    combined_df_fit["P"] = rainfall_black_volta["P"]
    combined_df_fit["E"] = factor_evap * df_temperature_msum["E"]
    combined_df_fit["Diff"] = combined_df_fit["P"] - combined_df_fit["Q"] -␣
↪combined_df_fit["E"]

    # compute
```

```
    yearly_sum = combined_df_fit[f'{year}'].sum()
    out = yearly_sum.P - yearly_sum.Q - yearly_sum.E
    if return_df:
        return combined_df_fit
    else:
        return out
```

[46]:
```
lst_dfs_fobj_input = [discharge_black_volta_msum_sorted, rainfall_black_volta,␣
 ↪df_temperature_msum]
sol = root(fobj, 0.3, args=(lst_dfs_fobj_input, year))
sol.x[0]
```

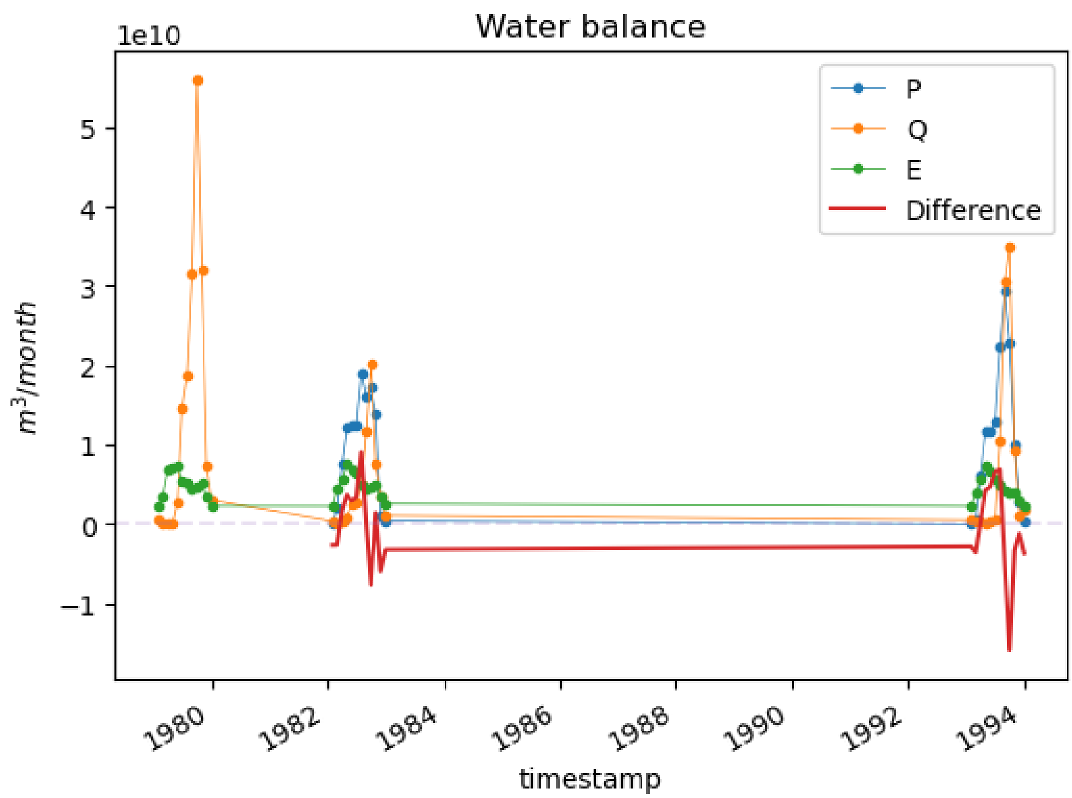
[46]: 0.3227556842505071

[47]:
```
combined_fitted_df = fobj(sol.x[0], lst_dfs_fobj_input,year, True)
yearly_balance = fobj(sol.x[0], lst_dfs_fobj_input,year, False)
yearly_balance
```

[47]: 0.0

[48]:
```
def plot_combined_df(combined_df):
    fig, ax = plt.subplots(1)
    ax.set_xlabel("Date")
    ax.set_ylabel("$m^3/month$")
    for val in ["P","Q","E"]:
        combined_df[val].plot(marker='.',lw=0.5, ax=ax,label=val)

    combined_df["Diff"].plot(ax=ax,label="Difference")
    ax.get_xlim()
    ax.set_title(f"Water balance")
    ax.legend()
    ax.axhline(0, alpha=0.2, ls="--", color="C4" )
```

[49]:
```
plot_combined_df(combined_fitted_df)
```



For presentation

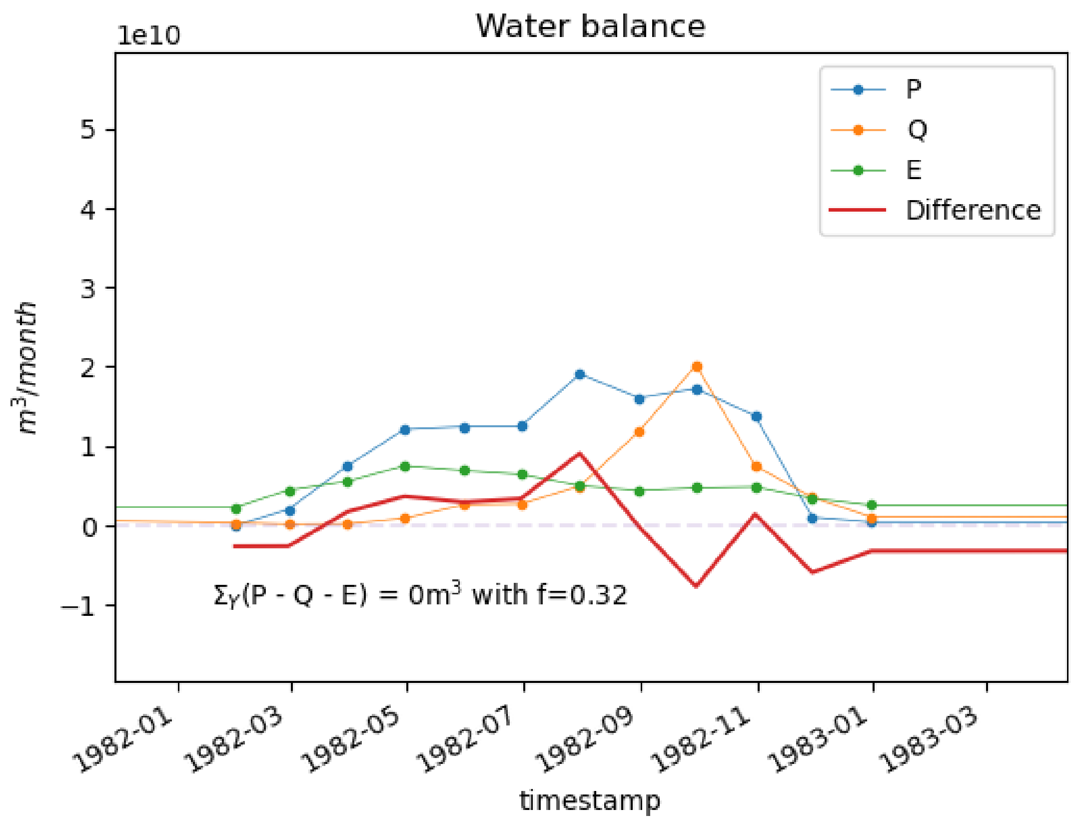
[50]:
```
yearly_sum_fitted = combined_fitted_df['1982'].sum()
print(f'{yearly_sum_fitted.P - yearly_sum_fitted.Q - yearly_sum_fitted.E:.2g}')
```

0

[51]:
```
fig, ax = plt.subplots(1)
ax.set_xlabel("Date")
ax.set_ylabel("$m^3/month$")
for val in ["P","Q","E"]:
    combined_fitted_df[val].plot(marker='.',lw=0.5, ax=ax,label=val)

combined_fitted_df["Diff"].plot(ax=ax,label="Difference")
ax.set_xlim((4350,4850))
ax.get_xlim()
ax.set_title(f"Water balance")
ax.legend()
ax.axhline(0, alpha=0.2, ls="--", color="C4" )

ax.annotate(f'$\Sigma_Y$(P - Q - E) = {yearly_sum_fitted.P - yearly_sum_fitted.
↪Q - yearly_sum_fitted.E:.2g}m$^3$'\
```

```
+ f' with f={sol.x[0]:.2f}'
,
(4400, -1e10))
```

[51]: Text(4400, -10000000000.0, '$\\Sigma_Y$(P - Q - E) = 0m^3 with f=0.32')



4 make general

5 moved to *Combining data sources - Finding Ea = f x Ep.ipynb*

[ ]:

Combining data sources - Finding Ea = f x Ep

March 3, 2023

import packages

[1]:
```
import glob
import os

# data/plot management
import pandas as pd
import matplotlib
import matplotlib.pyplot as plt
import numpy as np

import warnings

# plotting/mapmaknig
import geopandas as gpd
from geospatial_functions import get_background_map
import rasterio
from rasterio.plot import show as rioshow
import folium

# adding 'custom script'
#Ensure the [Pyeto](https://github.com/woodcrafty/PyETo) package is present in␣
↪your
# "C:\Users\{USERNAME}\anaconda3\envs\{ENVIRONMENT}\Lib\",or "C:
↪\Users\{USERNAME}\anaconda3\Lib\",
from pyeto import thornthwaite, monthly_mean_daylight_hours, deg2rad

from scipy.optimize import root

warnings.simplefilter('ignore')
```

add some useful paths to navigate shared storage:

[2]:
```
path = os.getcwd()
home_path = os.path.dirname(path)
main_folder = os.path.dirname(home_path)

gis_folder = f'{main_folder}\\QGIS project'
```

add some spatial data

[3]:
```
country_outline = gpd.read_file(f"{gis_folder}\\country_outline_32630.gpkg")
volta_outline = gpd.read_file(f"{gis_folder}\\volta_watershed_vector_32630.
 ↪gpkg",crs="epsg:32630")
main_rivers = gpd.read_file(f"{gis_folder}\\main_rivers_volta.gpkg",crs="epsg:
 ↪32630")

country_outline = country_outline.set_geometry(country_outline.geometry.
 ↪to_crs('EPSG:4326'))
volta_outline = volta_outline.set_geometry(volta_outline.geometry.to_crs('EPSG:
 ↪4326'))
main_rivers = main_rivers.set_geometry(main_rivers.geometry.to_crs('EPSG:4326'))

gdf_discharge_client = gpd.read_file('discharge_data_client.geojson',crs="EPSG:
 ↪4326")
gdf_discharge_client['name'] = gdf_discharge_client.apply(lambda x: x['name'].
 ↪split(",")[-1][:-4].strip().lower(),axis=1)
```

1 make general:

load precipitation data from analysis

[4]:
```
Rainfall_BF_msum = pd.read_excel("Monthly_sum_rainfall.xlsx",index_col=0)
Rainfall_BF_msum.columns
```

[4]:
```
Index(['Ouagadougou', 'Nakambe', 'Black_Volta', 'Mouhoun', 'Lake_Volta', 'Oti',
       'Penjari'],
      dtype='object')
```

[5]:
```
Rainfall_BF_msum.head()
```

[5]:
```
            Ouagadougou    Nakambe  Black_Volta    Mouhoun  Lake_Volta  \
Date
1981-01-31     0.000000   0.000000     0.410630   0.000000   13.869179
1981-02-28     0.000000   0.146212     3.206854   0.440967   52.009327
1981-03-31     3.321553   2.109617    90.963905   6.727890  181.174277
1981-04-30    31.308575   7.266831    63.252223  17.095812  113.174518
1981-05-31    78.591566  35.860808   140.261632  77.489709  207.591562

                   Oti    Penjari
Date
1981-01-31    0.000000   0.000000
1981-02-28    4.207938   0.000000
1981-03-31  106.531309  13.677208
1981-04-30   48.240848  69.913232
1981-05-31  161.008969  173.526988
```

load discharge data from analysis

[6]:
```
names = ['black volta, vonkoro',
         'bougouriba, dan',
         'mou houn, black volta, samandeni',
         'mou houn, black volta,dapola',
         'nakanbe, white volta, yakala',
         'nakanbe, white volta, yilou',
         'nazinon, red volta, dakaye',
         'pendjari, porga',
         'singou, samboali']
```

need a dictionary to link discharge to precipitation stations

[7]:
```
q_p_linking_dictionary = {'black volta, vonkoro': 'Black_Volta',
                          'bougouriba, dan': 'Mouhoun',
                          'mou houn, black volta, samandeni': 'Mouhoun',
                          'mou houn, black volta,dapola': 'Black_Volta',
                          'nakanbe, white volta, yakala': 'Nakambe',
                          'nakanbe, white volta, yilou': 'Nakambe',
                          'nazinon, red volta, dakaye': 'Nakambe',
                          'pendjari, porga': 'Penjari',
                          'singou, samboali': 'Penjari'}
```

[8]:
```
df_discharge_per_location_lst = []
for name in names:
    df_discharge = pd.read_excel(f"{home_path}\\Combining data\\{name}.
↪xlsx",index_col=0)
    df_discharge_per_location_lst.append(df_discharge)
```

1.1 Q

[9]:
```
df_discharge_lst = []
for index, df in enumerate(df_discharge_per_location_lst):
    name = names[index]
    df_discharge_location = df_discharge_per_location_lst[index].
↪rename(columns={name:"Q"})
    # get month with data
    months_with_data = df_discharge_location.apply(lambda x: f'{x.name.
↪month}-{x.name.year}', axis=1).unique()

    # get monthly sum
    df_discharge = df_discharge_location.resample('M').sum()

    # do indexing magic to discard non-data-eyars
    df_discharge['timestamp'] = df_discharge.apply(lambda x: x.name, axis=1)
    df_discharge.index = df_discharge.apply(lambda x: f'{x.name.month}-{x.name.
↪year}', axis=1)
```

```
    df_discharge = df_discharge.loc[months_with_data]
    df_discharge.index = df_discharge['timestamp']
    df_discharge.drop(columns="timestamp",inplace=True)
    df_discharge.Q = df_discharge.apply(lambda x: x.Q * x.name.days_in_month *␣
↪24 * 3600 , axis=1)
    df_discharge_lst.append(df_discharge)
```

1.2 E

historic temperature data downloaded from CMIP6 model from NOAA-GFDL -

[10]:
```
df_temperature = pd.
↪read_excel(f"{home_path}\\Evaporation\\daily_Near-Surface-Air-Temperature.
↪xlsx",
# df_temperature = pd.
↪read_excel(f"{home_path}\\Evaporation\\mean_monthly_Near-Surface-Air-Temperature.
↪xlsx",
                             index_col=0, parse_dates=True)
df_temperature.rename(columns={0:"Temperature"},inplace=True)
df_temperature_msum = df_temperature.resample('M').mean()
```

dakaye was chosen to as fairly centrally located

[11]:
```
lat = deg2rad(gdf_discharge_client[gdf_discharge_client['name']=="dakaye"].
↪iloc[0].geometry.y)
```

[12]:
```
years = df_temperature_msum.index.year.unique()
for year in years:
    mmdlh = monthly_mean_daylight_hours(lat, year)
    # use thornthwaite to calculate the
    evap = thornthwaite(df_temperature_msum[f'{year}'].Temperature.to_list(),␣
↪mmdlh, year=year)
    set_items = df_temperature_msum[f'{year}'].index
    df_temperature_msum.loc[set_items,"evap"] = evap
```

2 some function

[13]:
```
def fobj_generalised(factor_evap, lst_dfs, year, return_df=False):
    """objective function to find the `factor_evap` which is the percentage of␣
↪potential evaporation actually present"""
    # unpack
    df_discharge = lst_dfs[0]
    rainfall_selected_basin = lst_dfs[1]
    df_local_evaporation = lst_dfs[2]

    combined_df = df_discharge.copy()
    combined_df["P"] = rainfall_selected_basin["P"]
```

```
    combined_df["E"] = factor_evap * df_local_evaporation["E"]
    combined_df["Diff"] = combined_df["P"] - combined_df["Q"] - combined_df["E"]
    combined_df = combined_df.loc[combined_df.P.dropna().index] # remove lack␣
↪of Precipitation data

    # compute
    yearly_sum = combined_df[f'{year}'].sum()
    out = yearly_sum.P - yearly_sum.Q - yearly_sum.E
    if return_df:
        return combined_df
    else:
        return out
```

[14]:
```
def plot_combined_df(combined_df):
    """Plots the combined_dfs constructed"""
    fig, ax = plt.subplots(1)
    ax.set_xlabel("Date")
    ax.set_ylabel("$m^3/month$")
    for val in ["P","Q","E"]:
        combined_df[val].plot(marker='.',lw=0.5, ax=ax,label=val)

    combined_df["Diff"].plot(ax=ax,label="Difference")
    ax.get_xlim()
    ax.set_title(f"Water balance")
    ax.legend()
    ax.axhline(0, alpha=0.2, ls="--", color="C4" )
```

3 now run per station:

[15]:
```
output_coefficients_df = []
for station_index in range(len(names)):
    # get corresponding names
    station_name = names[station_index]
    station_precip = q_p_linking_dictionary[station_name]

    # do geoanalysis
    point_discharge = gdf_discharge_client.iloc[station_index].geometry.
↪buffer(0.05)
    selected_segement =  main_rivers[main_rivers.crosses(point_discharge)]

    if len(selected_segement) < 1:
        print("no river segment found")
        # error in finding river segment, we stop
    else:
        # get the first segment to enter the buffer around the station
        selected_location = main_rivers.loc[selected_segement.index[0],:]
```

```
        # retreive the area
        selected_basin_area = selected_location.UPLAND_SKM* 10**6  # km^2 -> m^2

        # get precipitation
        rainfall_selected_basin = Rainfall_BF_msum[[station_precip]].
↪rename(columns={station_precip:"P"})
        rainfall_selected_basin.P = rainfall_selected_basin.P *␣
↪selected_basin_area / 1000 # mm/month * m^2 ->/1000

        # get evaporation
        df_local_evaporation = df_temperature_msum[['evap']] *␣
↪selected_basin_area / 1000 # mm/month * m^2 ->/1000
        df_local_evaporation.rename(columns={'evap':'E'},inplace=True)
        ### do initial compute, but E will be too high
        combined_df = df_discharge_lst[station_index].copy()
        combined_df["P"] = rainfall_selected_basin["P"]
        combined_df["E"] = df_local_evaporation["E"]
        combined_df["Diff"] = combined_df["P"] - combined_df["Q"] -␣
↪combined_df["E"]
        combined_df = combined_df.loc[combined_df.P.dropna().index] # remove␣
↪lack of Precipitation data
        # some cases no overlap in data
        if len(combined_df) > 0:

            lst_coefficients = []
            for year in combined_df.index.year.unique():
                if len(df_discharge_lst[station_index][f'{year}']) < 10:
                    # remove year with too few observations
                    pass
                else:
                    lst_dfs_fobj_input = [df_discharge_lst[station_index],␣
↪rainfall_selected_basin, df_local_evaporation]
                    sol = root(fobj_generalised, 1.2, args=(lst_dfs_fobj_input,␣
↪year))
                    lst_coefficients.append(sol.x[0])
#                     df_fitted= fobj_generalised(sol.x[0],␣
↪lst_dfs_fobj_input,year, True)



            location_lst = [station_name for i in range(len(lst_coefficients))]
            output_df = pd.DataFrame(columns=['Year',"Factor","Location"],
                                     data=list(zip(combined_df.index.year.
↪unique(), lst_coefficients, location_lst)))
            output_df.index.name = station_name
            output_coefficients_df.append(output_df)
```

```
            print(output_df)
```

```
                      Year    Factor              Location
black volta, vonkoro
0                     1982  0.322133  black volta, vonkoro
1                     1993  0.243763  black volta, vonkoro
                 Year    Factor         Location
bougouriba, dan
0                1981 -0.233770  bougouriba, dan
1                1982 -0.078619  bougouriba, dan
2                1983  0.294991  bougouriba, dan
no river segment found
                             Year    Factor                     Location
nakanbe, white volta, yilou
0                            1981 -0.020288  nakanbe, white volta, yilou
1                            1982  0.293072  nakanbe, white volta, yilou
no river segment found
                 Year    Factor         Location
pendjari, porga
0                1981 -0.123541  pendjari, porga
1                1982 -0.008848  pendjari, porga
2                1983  0.027523  pendjari, porga
3                1984  0.209215  pendjari, porga
4                1990  0.069535  pendjari, porga
no river segment found
```

[16]:

```
combined_factors = pd.concat(output_coefficients_df)
combined_factors.sort_values("Year",inplace=True)
combined_factors.reset_index(inplace=True,drop=True)
```

[17]:

```
fig, ax = plt.subplots(1)
ax.plot(combined_factors["Year"].values,combined_factors["Factor"].
 ↪values,marker='.', lw=0)
ax.set_ylim(0,0.5)
# median_factor = combined_factors["Factor"][combined_factors["Factor"]>0.2].
 ↪median()
# ax.axhline(median_factor,color="g",alpha=0.3)

mean_factor = combined_factors["Factor"][combined_factors["Factor"]>0.2].mean()
ax.axhline(mean_factor,color="r",alpha=0.3)

ax.set_xlabel("year")
ax.set_ylabel("Factor Ea of Ep")
ax.set_title(f"Results from different model fits with $\mu$:{mean_factor:.4f}")
```

[17]:

```
Text(0.5, 1.0, 'Results from different model fits with $\\mu$:0.2726')
```


Results from different model fits with μ:0.2726
Factor Ea of Ep
0.0
0.1
0.2
0.3
0.4
0.5
1982
1984
1986
1988
1990
1992
year

Combining data sources - General water supply

March 3, 2023

import packages

[1]:
```
import glob
import os

# data/plot management
import pandas as pd
import matplotlib
import matplotlib.pyplot as plt
import numpy as np

import warnings

# plotting/mapmaknig
import geopandas as gpd
from geospatial_functions import get_background_map
import rasterio
from rasterio.plot import show as rioshow
import folium

# adding 'custom script'
#Ensure the [Pyeto](https://github.com/woodcrafty/PyETo) package is present in␣
↪your
# "C:\Users\{USERNAME}\anaconda3\envs\{ENVIRONMENT}\Lib\",or "C:
↪\Users\{USERNAME}\anaconda3\Lib\",
from pyeto import thornthwaite, monthly_mean_daylight_hours, deg2rad

from scipy.optimize import root

warnings.simplefilter('ignore')
```

add some useful paths to navigate shared storage:

[2]:
```
path = os.getcwd()
home_path = os.path.dirname(path)
main_folder = os.path.dirname(home_path)

gis_folder = f'{main_folder}\\QGIS project'
```

add some spatial data

[3]:
```
country_outline = gpd.read_file(f"{gis_folder}\\country_outline_32630.gpkg")
volta_outline = gpd.read_file(f"{gis_folder}\\volta_watershed_vector_32630.
↪gpkg",crs="epsg:32630")
main_rivers = gpd.read_file(f"{gis_folder}\\main_rivers_volta.gpkg",crs="epsg:
↪32630")
all_rivers_bf = gpd.read_file(f"{gis_folder}\\all_river_in_volta_basin_bf.
↪gpkg",crs="epsg:32630")

country_outline = country_outline.set_geometry(country_outline.geometry.
↪to_crs('EPSG:4326'))
volta_outline = volta_outline.set_geometry(volta_outline.geometry.to_crs('EPSG:
↪4326'))
main_rivers = main_rivers.set_geometry(main_rivers.geometry.to_crs('EPSG:4326'))
all_rivers_bf = all_rivers_bf.set_geometry(all_rivers_bf.geometry.to_crs('EPSG:
↪4326'))

gdf_precip = gpd.read_file('precipitation_data_client.geojson',crs="EPSG:4326")
gdf_discharge_client = gpd.read_file('discharge_data_client.geojson',crs="EPSG:
↪4326")
gdf_discharge_client['name'] = gdf_discharge_client.apply(lambda x: x['name'].
↪split(",")[-1][:-4].strip().lower(),axis=1)
```

[4]:
```
gdf_discharge_client
```

[4]:

	name	lat	lon	geometry
0	vonkoro	9.171205	-2.744841	POINT (-2.74484 9.17121)
1	dan	10.867876	-3.722479	POINT (-3.72248 10.86788)
2	samandeni	11.458715	-4.469477	POINT (-4.46948 11.45872)
3	dapola	10.572862	-2.914135	POINT (-2.91413 10.57286)
4	yakala	11.344608	-0.528965	POINT (-0.52897 11.34461)
5	yilou	12.999710	-1.570603	POINT (-1.57060 12.99971)
6	dakaye	11.777456	-1.600156	POINT (-1.60016 11.77746)
7	porga	11.045433	0.959914	POINT (0.95991 11.04543)
8	samboali	11.279537	1.015889	POINT (1.01589 11.27954)

1 make general:

load precipitation data from analysis

[5]:
```
Rainfall_BF_msum = pd.read_excel("Monthly_sum_rainfall.xlsx",index_col=0)
Rainfall_BF_msum.columns
```

[5]:
```
Index(['Ouagadougou', 'Nakambe', 'Black_Volta', 'Mouhoun', 'Lake_Volta', 'Oti',
       'Penjari'],
      dtype='object')
```

load discharge data from analysis

[6]:
```
names = ['black volta, vonkoro',
         'bougouriba, dan',
         'mou houn, black volta, samandeni',
         'mou houn, black volta,dapola',
         'nakanbe, white volta, yakala',
         'nakanbe, white volta, yilou',
         'nazinon, red volta, dakaye',
         'pendjari, porga',
         'singou, samboali']
```

need a dictionary to link discharge to precipitation stations

[7]:
```
q_p_linking_dictionary = {'black volta, vonkoro': 'Black_Volta',
                          'bougouriba, dan': 'Mouhoun',
                          'mou houn, black volta, samandeni': 'Mouhoun',
                          'mou houn, black volta,dapola': 'Black_Volta',
                          'nakanbe, white volta, yakala': 'Nakambe',
                          'nakanbe, white volta, yilou': 'Nakambe',
                          'nazinon, red volta, dakaye': 'Nakambe',
                          'pendjari, porga': 'Penjari',
                          'singou, samboali': 'Penjari'}
```

[8]:
```
df_discharge_per_location_lst = []
for name in names:
    df_discharge = pd.read_excel(f"{home_path}\\Combining data\\{name}.
 ↪xlsx",index_col=0)
    df_discharge_per_location_lst.append(df_discharge)
```

1.1 E

historic temperature data downloaded from CMIP6 model from NOAA-GFDL -

[9]:
```
df_temperature = pd.
 ↪read_excel(f"{home_path}\\Evaporation\\daily_Near-Surface-Air-Temperature.
 ↪xlsx",
# df_temperature = pd.
 ↪read_excel(f"{home_path}\\Evaporation\\mean_monthly_Near-Surface-Air-Temperature.
 ↪xlsx",
                           index_col=0, parse_dates=True)
df_temperature.rename(columns={0:"Temperature"},inplace=True)
df_temperature_msum = df_temperature.resample('M').mean()
```

`dakaye` was chosen to as fairly centrally located

[10]:
```
lat = deg2rad(gdf_discharge_client[gdf_discharge_client['name']=="dakaye"].
 ↪iloc[0].geometry.y)
```

```
[11]: years = df_temperature_msum.index.year.unique()
for year in years:
    mmdlh = monthly_mean_daylight_hours(lat, year)
    # use thornthwaite to calculate the
    evap = thornthwaite(df_temperature_msum[f'{year}'].Temperature.to_list(),␣
 ↪mmdlh, year=year)
    set_items = df_temperature_msum[f'{year}'].index
    df_temperature_msum.loc[set_items,"evap"] = evap
```

2 some function

```
[12]: def plot_combined_df(combined_df):
    """Plots the combined_dfs constructed"""
    fig, ax = plt.subplots(1)
    ax.set_xlabel("Date")
    ax.set_ylabel("$m^3/month$")
    for val in ["P","Q","E"]:
        combined_df[val].plot(marker='.',lw=0.5, ax=ax,label=val)

    combined_df["Diff"].plot(ax=ax,label="Difference")
    ax.get_xlim()
    ax.set_title(f"Water balance")
    ax.legend()
    ax.axhline(0, alpha=0.2, ls="--", color="C4" )
```

```
[13]: FACTOR_EA_EP = 0.2726
```

```
[14]: output_river = all_rivers_bf.copy()
```

3 now run per river segment:

```
[15]: for index, row in all_rivers_bf.iterrows():
    # get the centre of each segment
    centre = row.geometry.centroid
    # find nearest precipitation station:
    closest_station_index = gdf_precip.distance(centre).argmin()
    name_of_closest_station = gdf_precip.loc[closest_station_index, "name"]
    selected_rain_data = Rainfall_BF_msum[[name_of_closest_station]].
 ↪rename(columns={name_of_closest_station:"P"})

    #prepare evaporation data
    df_temperature_msum.rename(columns={'evap':'E'},inplace=True)
    area_basin = row.UPLAND_SKM * 10**6

    # adjust potential to actuall evaporation
    combined_df = area_basin * FACTOR_EA_EP * df_temperature_msum[["E"]].copy()
```

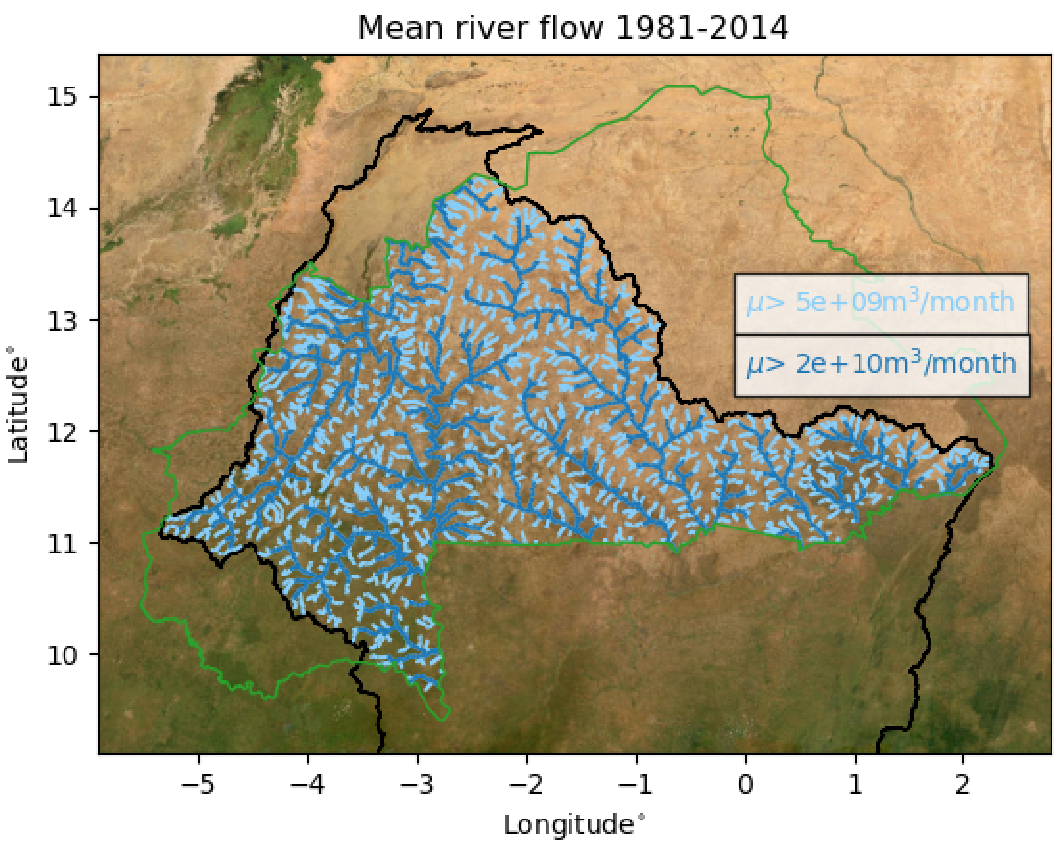
```
    # combine everything:
    combined_df["P"] = selected_rain_data["P"] * area_basin
    combined_df["Q"] = combined_df["P"] - combined_df["E"]
    combined_df = combined_df.loc[combined_df.P.dropna().index]
    combined_df = combined_df[combined_df["Q"] >= 0]
    combined_df = combined_df.resample('M').mean()
#     combined_df['Q_ms'] = combined_df.apply(lambda x: x.Q / (x.name.
↪days_in_month * 24 * 3600), axis=1)
#     combined_df["Q"].plot(marker='.', lw=1)

    output_river.loc[index,"MIN_1981_2014_M3"]   = combined_df['Q'].min()
    output_river.loc[index,"MAX_1981_2014_M3"]   = combined_df['Q'].max()
    output_river.loc[index,"MEAN_1981_2014_M3"]  = combined_df['Q'].mean()
```

[16]:
```
output_river.head(1)
```

[16]:
```
   HYRIV_ID  NEXT_DOWN  MAIN_RIV  LENGTH_KM  DIST_DN_KM  DIST_UP_KM  \
0  10482758   10483017  10821582       2.43      1763.0         9.5

   CATCH_SKM  UPLAND_SKM  ENDORHEIC  DIS_AV_CMS  ORD_STRA  ORD_CLAS  ORD_FLOW  \
0      15.19        15.2          0       0.002         1         6         9

    HYBAS_L12                                            geometry  \
0  1121891670  LINESTRING (-2.41667 14.26458, -2.42292 14.264…

   MIN_1981_2014_M3  MAX_1981_2014_M3  MEAN_1981_2014_M3
0      3.209353e+06      3.978544e+09       1.489383e+09
```

[17]:
```
fig,ax = plt.subplots(1)
country_outline.plot(ax=ax, facecolor="none", edgecolor="C2",zorder=6)
bounds= (ax.get_xlim()[0], ax.get_ylim()[0], ax.get_xlim()[1], ax.get_ylim()[1])
volta_outline.plot(ax=ax,edgecolor="k", facecolor='none')
# add background
with rasterio.open(get_background_map("rivers", bounds)) as r:
    rioshow(r, ax=ax)

ax.set_xlim(bounds[0],bounds[2])
ax.set_ylim(bounds[1],bounds[3])
stats = output_river["MEAN_1981_2014_M3"].describe()
output_river[output_river["MEAN_1981_2014_M3"]>stats[f'50%']].
↪plot(ax=ax,color=f'lightskyblue')
legend1 = ax.annotate(f"$\mu$> {stats[f'50%']:.1g}m$^3$/month", (0,13.
↪05),color='lightskyblue',zorder=10)#,
#             path_effects=[matplotlib.patheffects.withStroke(linewidth=0.25,␣
↪foreground="k")],zorder=10)
```

```
output_river[output_river["MEAN_1981_2014_M3"]>stats[f'75%']].plot(ax=ax,color=f'C0')
legend2 = ax.annotate(f"$\mu$> {stats[f'75%']:.1g}m$^3$/month", (0,12.5),color='C0',zorder=10)#,
#              path_effects=[matplotlib.patheffects.withStroke(linewidth=0.25, foreground="k")],zorder=10)

legend1.set_bbox(dict(facecolor='w', alpha=0.8))
legend2.set_bbox(dict(facecolor='w', alpha=0.8))

ax.set_xlabel("Longitude$^{\circ}$");
ax.set_ylabel("Latitude$^{\circ}$");
ax.set_title("Mean river flow 1981-2014")

fig.savefig('rivers_flow.png', transparent=True)
```



[18]:
```
output = False
if output:
```

```
    output_river.to_file(f"{gis_folder}\\all_river_in_volta_basin_bf_with_Q.
↪gpkg",crs="epsg:4326")
```

[ ]:

```

```