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International Water Resources Association
IWRA

XIX WORLD WATER CONGRESS
International Water Resources Association (IWRA)
Marrakech, Morocco | 1 - 5 December 2025

Kingdom of Morocco
Ministry of Equipment and Water

Assessing Future Drought Risk in the Maamora Aquifer Using High-Resolution Climate Projections and standardized indices

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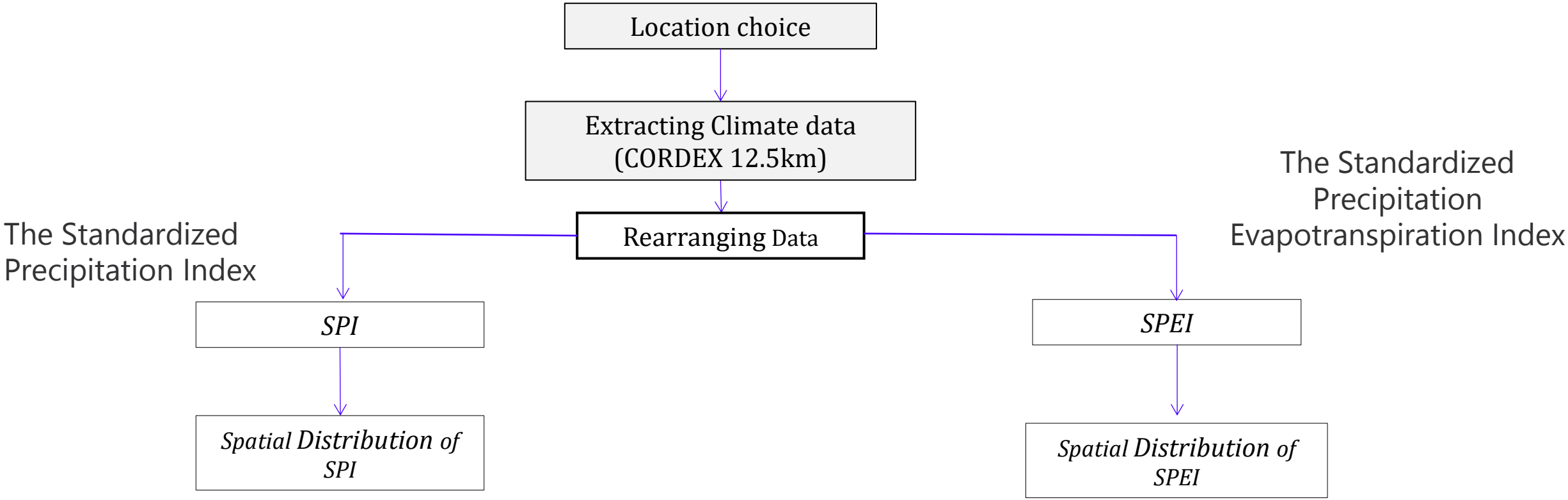
Mohammadia School of Engineers (EMI), Mohammed V University,
Rabat, Morocco

3 DECEMBER 2025

Adopted methodology



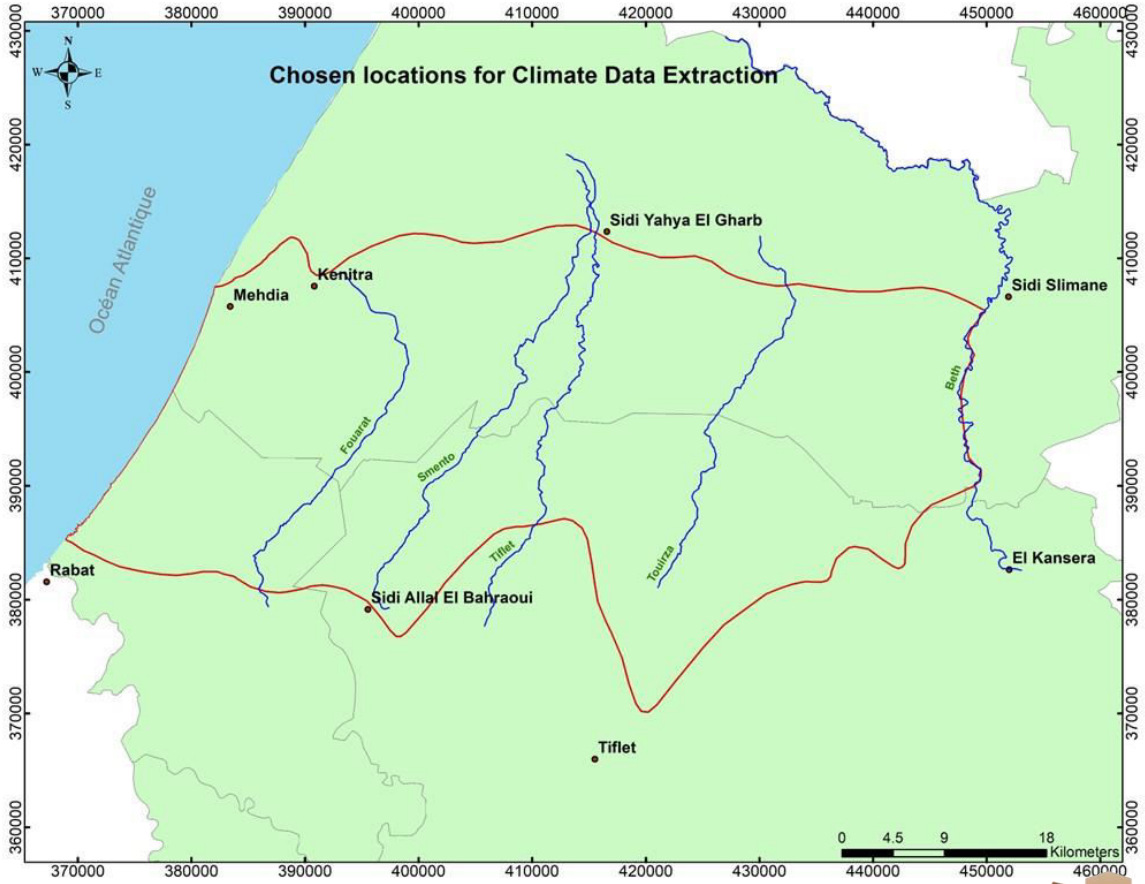
I. Study Area And Climate Data

Study Area

- At the regional scale, the **Maamora aquifer** is one of the most important groundwater reserves in Morocco.
- It supplies drinking water to the cities of Kénitra, Salé, and the surrounding urban areas along the coast.
- In the past, it supplied drinking water to the city of Casablanca (before the construction of the Sidi Mohammed Ben Abdellah dam) as well as all the surrounding urban areas.

Table: Coordinates of chosen locations (WGS 84)

City	Longitude	Latitude
Sidi Slimane	-5.921845	34.26038
Kenitra	-6.585575	34.26421
Tiflet	-6.313388	33.89158
Sidi Yahya El Gharb	-6.306278	34.30979
Sidi Allal El Bahraoui	-6.531024	34.00853
Mehdia	-6.665681	34.24731
Rabat	-6.837574	34.02724
El Kansera	-5.92	34.0441



Dataset

CORDEX (Coordinated Regional Climate Downscaling Experiment)

An international **research program** that produces **regional climate projections** for impact and adaptation studies.

We used CORDEX to get the **high-resolution** (available) temperature and precipitation data for the Maamora region **at 12.5km**

Best results for North Atlantic regions, and decent results for Mediterranean region.

The model output includes crucial climate variables like **precipitation** and **temperature at 12.5km**, under two Representative Concentration Pathway (**RCP4.5 & RCP8.5**) for **2025-2100**

ESGF MetaGrid :https://esgf-metagrid.cloud.dkrz.de/search/cordex-dkrz/

Extracting Data

```
% Define root path and coordinates of interest
rootDir = 'G:\Projet_Maamoura_2024\EuroCORDEX 12.5 km\Temperature';
lat_target = 34.0441;
lon_target = -5.92;


% ------------------ Load a reference file to locate nearest grid cell ------------------
refFile = fullfile(rootDir, 'RCP4.5\EC-EARTH', ...
    'tasAdjust_EUR-11_ICHEC-EC-EARTH_rcp45_r12i1p1_SMHI-RCA4_v1-SMHI_bias-corrected_WGS84_1970-1980_Morocco.nc');
lon = ncread(refFile, 'lon');
lat = ncread(refFile, 'lat');

[~, idxLat] = min(abs(lat - lat_target));
[~, idxLon] = min(abs(lon - lon_target));
fprintf('Selected Grid Point: Lat = %.3f, Lon = %.3f\n', lat(idxLat), lon(idxLon));


% ------------------ FUNCTION: Read Temperature from NetCDF ------------------
function [timeVec, tempData] = read_netcdf_temperature(directory, varName, idxLat, idxLon)
    Files = dir(fullfile(directory, '*.nc'));

    if isempty(Files)
```

MATLAB code to extract Temperature

```
% Define root path and coordinates of interest
rootDir = 'G:\Projet_Maamoura_2024\EuroCORDEX 12.5 km\Precipitation';
lat_target = 34.02724;
lon_target = -6.837574;


% Function to process NetCDF files
function [timeVec, precipData] = read_netcdf_data(directory, varName, idxLat, idxLon)
    % Get all NetCDF files in the directory
    Files = dir(fullfile(directory, '*.nc'));

    if isempty(Files)
        error('No .nc files found in: %s', directory);
    end
```

MATLAB code to extract Precipitation

Rearranging Data

Year	Month	PRCP	Tmin	Tmax
2025	1	104.181698	6.65737295	12.5892277
2025	2	68.99825155	10.3543339	18.6819401
2025	3	15.05289336	12.2034855	20.1072025
2025	4	30.9375531	14.1834049	23.5856266
2025	5	43.09917376	15.025629	23.6910954
2025	6	4.959343015	18.9046574	32.2358932
2025	7	2.203108661	24.4263248	34.1741562
2025	8	3.663962046	21.7736454	33.1072922
2025	9	14.91177367	19.0712528	26.5088749
2025	10	53.4666902	15.3955936	24.9016666
2025	11	134.2876416	13.9635868	18.5103092
2025	12	46.88406268	8.40606117	17.8723392
2026	1	27.20988522	7.87813711	13.5053959
2026	2	113.518681	9.71706581	13.8133793

Rearranged extracted Data according to analyses requirements

II. SPI and SPEI

SPI or SPEI Classification

Climatic moisture categories	SPI or SPEI
Extremely wet	≥ 2.0
Severely wet	1.5 to 1.99
Moderately wet	1.0 to 1.49
Normal	0.99 to − 0.99
Moderate drought	− 1.0 to − 1.49
Severe drought	− 1.5 to − 1.99
Extreme drought	≤ − 2.0

SPI or SPEI Classification

Year	PRC	SPI	Classification
2025	371.081	-0.47	Normal
2026	1156.95	3.74	Extremely wet
2027	237.711	-1.19	Moderate drought
2028	703.396	1.31	Moderately wet
2029	460.145	0.00	Normal
2030	655.462	1.05	Moderately wet
2031	278.529	-0.97	Normal
2032	1001.88	2.91	Extremely wet
2033	445.802	-0.07	Normal
2034	265.187	-1.04	Moderate drought
2035	493.889	0.19	Normal
2036	398.179	-0.33	Normal
2037	305.301	-0.83	Normal
2038	284.649	-0.94	Normal
2039	221.598	-1.27	Moderate drought
2040	524.243	0.35	Normal
2041	340.979	-0.63	Normal

SPI results n Rabat for RCP4.5 (2025-2100)

☑	SPEI	Calculation of the Standardized Precipitation-Evapotranspiration Index

Month	PRCP	Tmin	Tmax	pet	spei12
2	7.750224e+01	7.739648	12.64620	38.73989	-0.010342386
3	1.180085e+02	10.557520	18.52819	79.43489	0.231986934
4	1.193355e+02	11.031794	19.03207	94.42480	0.714582094
5	2.160963e+01	13.642115	25.29666	148.12366	0.448699984
6	8.568222e+00	18.284418	26.20803	131.84026	0.716741622
7	8.968207e-02	19.839197	31.04962	171.74115	0.697665145
8	3.731306e+00	20.600031	30.28069	147.30203	0.704160200
9	1.463583e+01	17.123590	26.00930	106.28253	0.684554105
10	4.072484e+01	14.781153	20.57873	63.82601	0.856548981
11	3.356329e+01	10.572718	19.88705	56.60883	0.994567431
12	3.170358e+01	7.570703	21.19433	60.02233	0.703101880
1	2.482326e+01	7.165155	16.17867	48.27226	0.560382927
2	2.011970e+02	8.460016	11.98385	32.86454	1.135114086

spei12 = 12-month accumulation period **ends** at that month.

SPEI for 2025 = **spei12 (December 2025)**

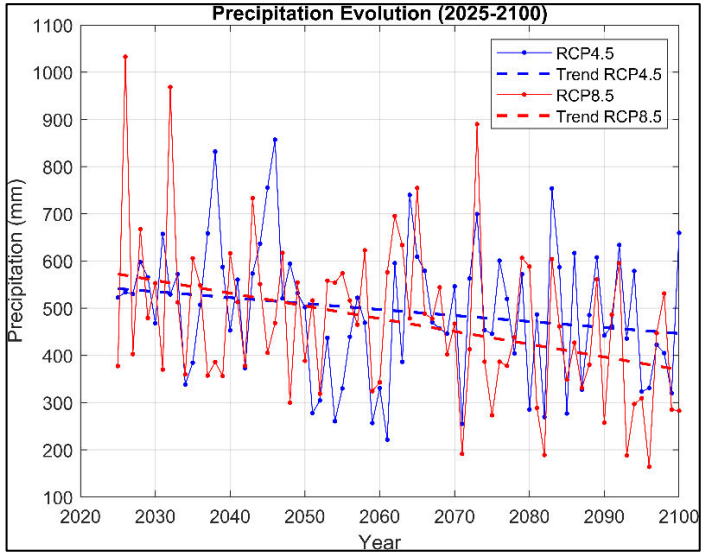
Year	Spei-12	Classification
2025	-0.49288712	Normal
2026	-0.29621248	Normal
2027	0.218070931	Normal
2028	1.320876319	Moderately wet
2029	0.902051248	Normal
2030	-0.48825582	Normal
2031	0.974481845	Normal
2032	0.802689072	Normal
2033	-0.49650381	Normal
2034	-1.48401027	Moderate drought
2035	-0.99792822	Moderate drought
2036	-0.50315035	Normal
2037	1.09737985	Moderately wet
2038	2.286610457	Extremely wet
2039	0.677172698	Normal
2040	-0.47492631	Normal
2041	-0.1861913	Normal

SPI results n Rabat for RCP4.5 (2025-2100)

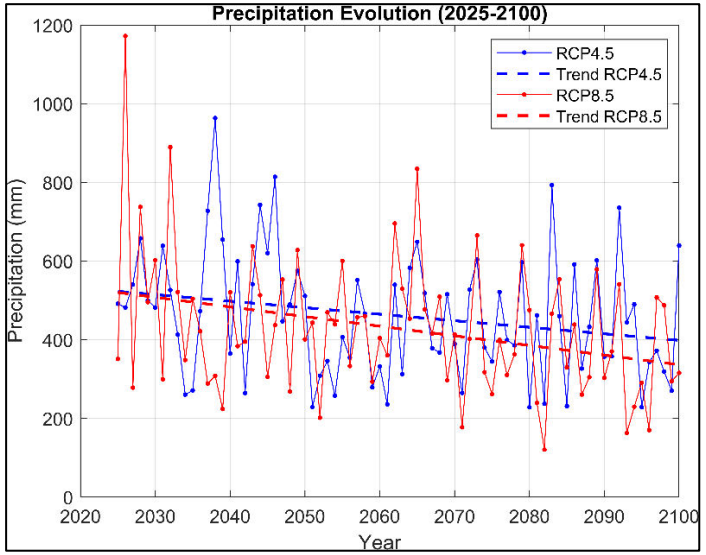
III. Data Analysis

Evolution of Precipitation

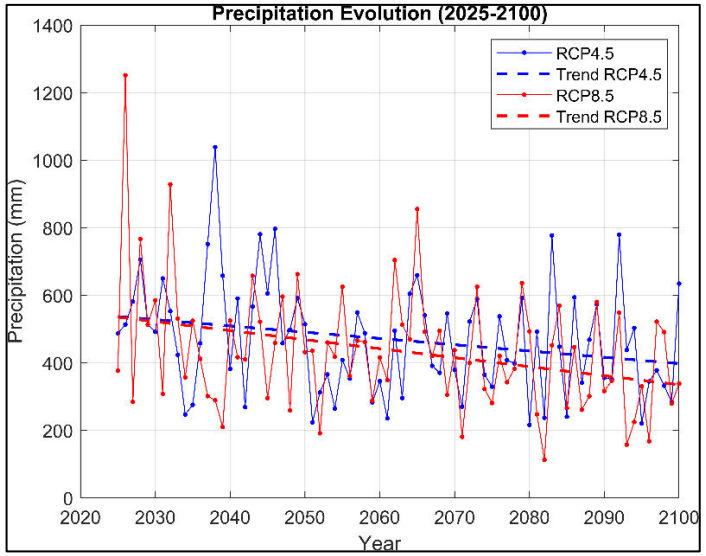
El Kansera



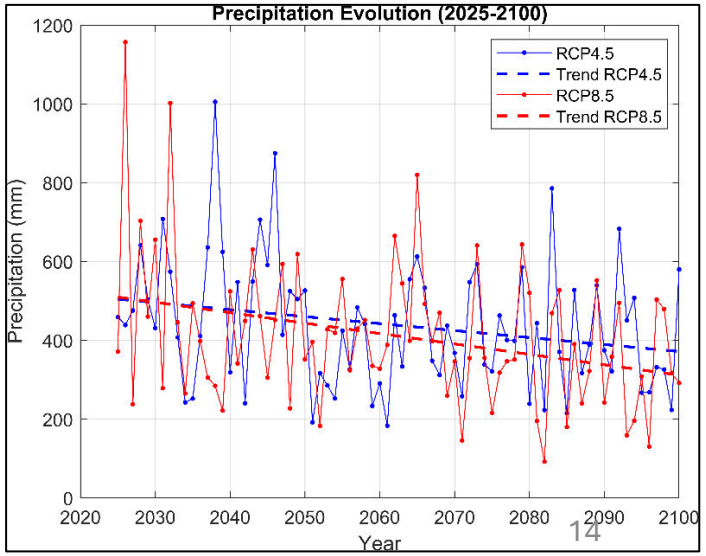
Kenitra



Mehdia

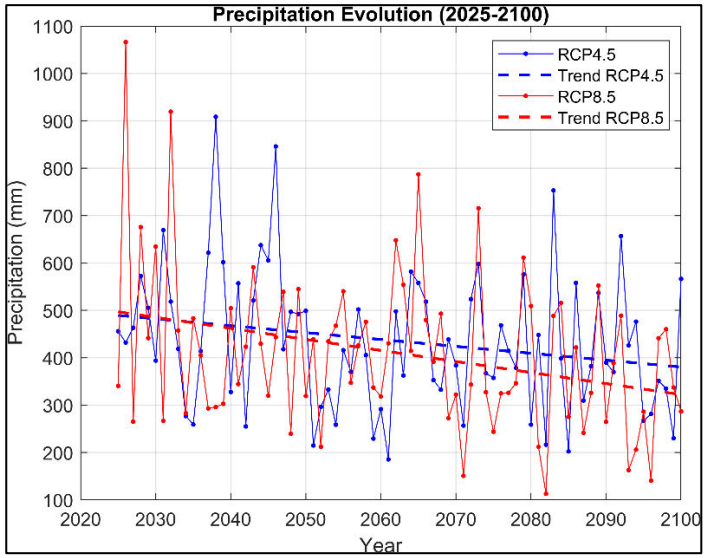


Rabat

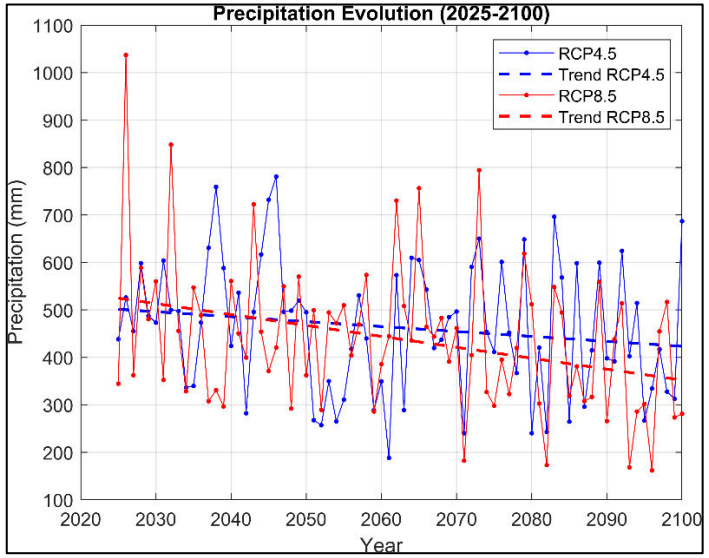


Evolution of Precipitation

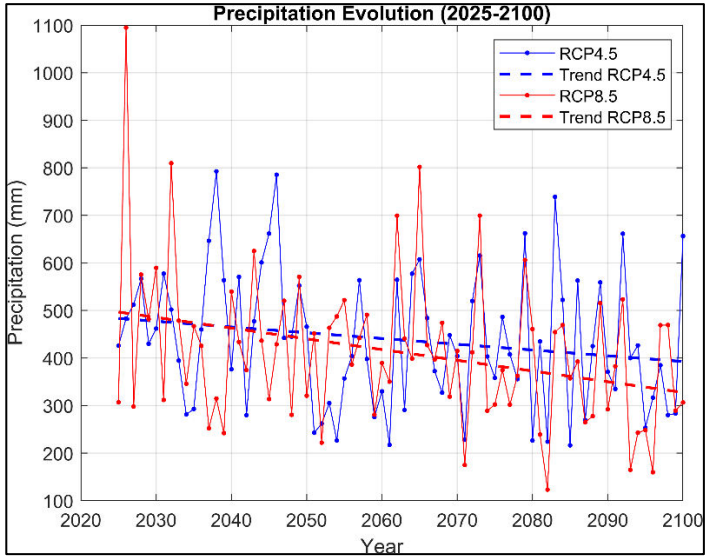
Sidi Allal El Bahraoui



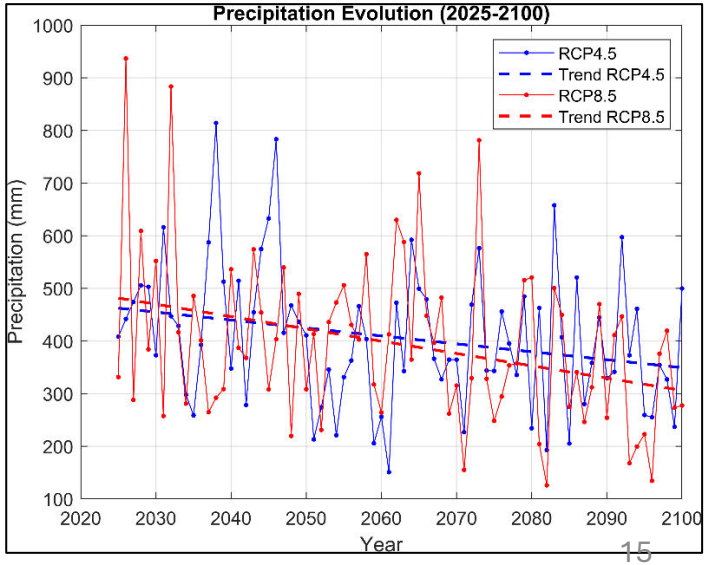
Sidi Slimane



Sidi Yahya El Gharb

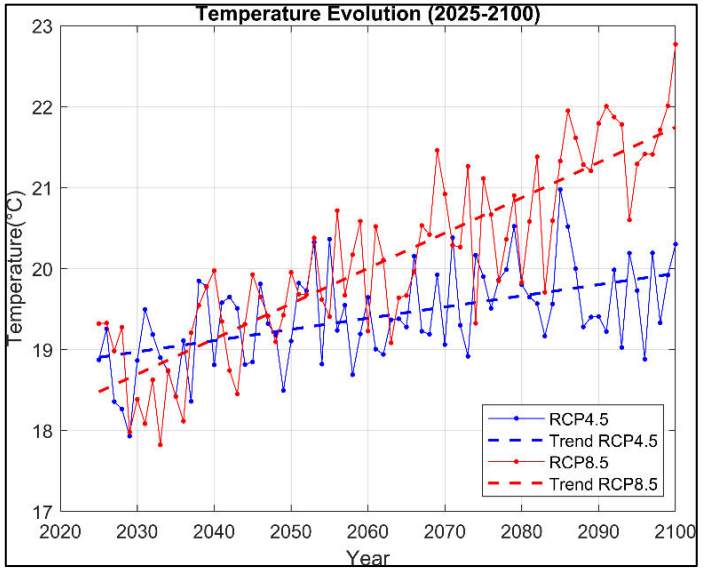


Tiflet

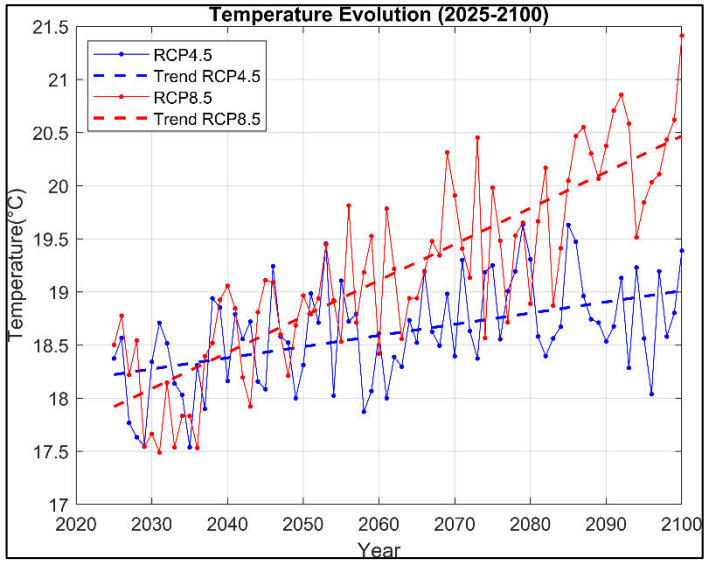


Evolution of Temperature

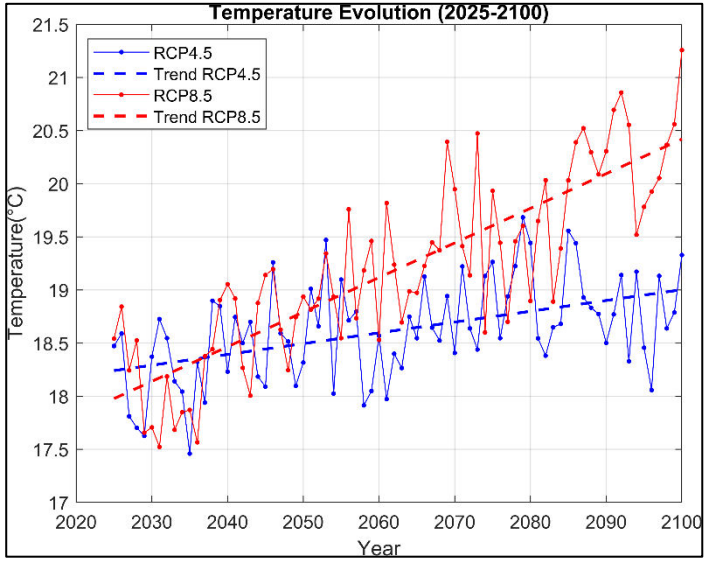
El Kansera



Kenitra



Mehdia



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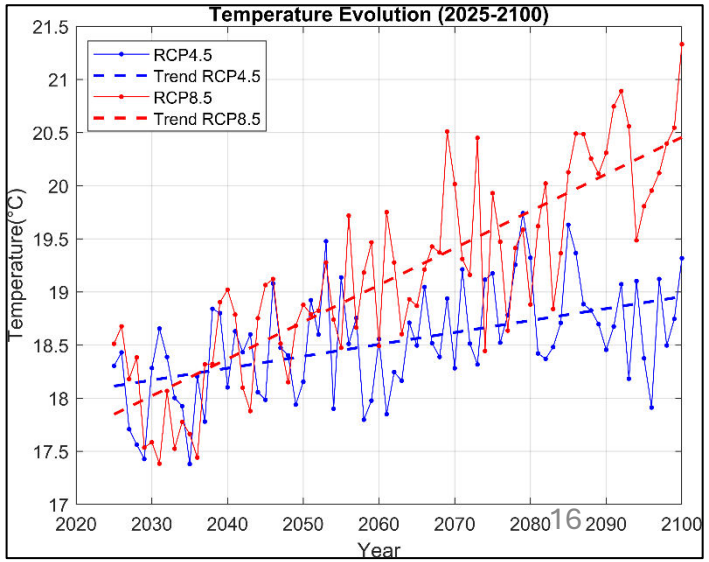
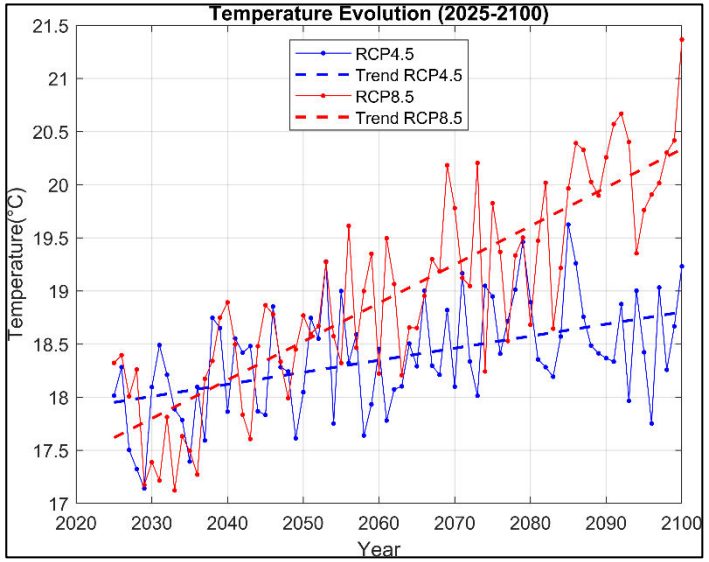
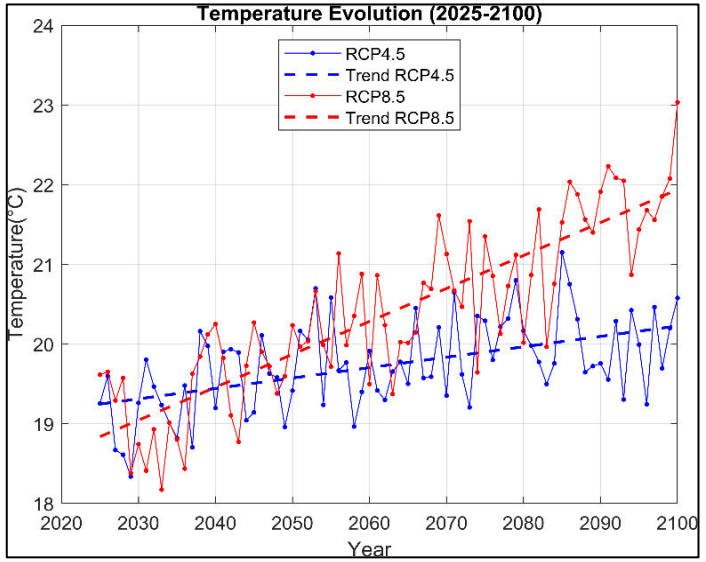


Evolution of Temperature

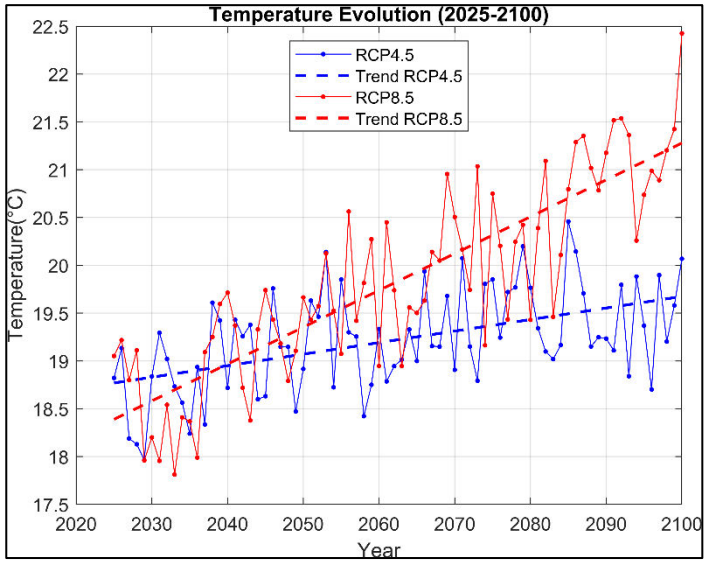
Sidi Allal El Bahraoui



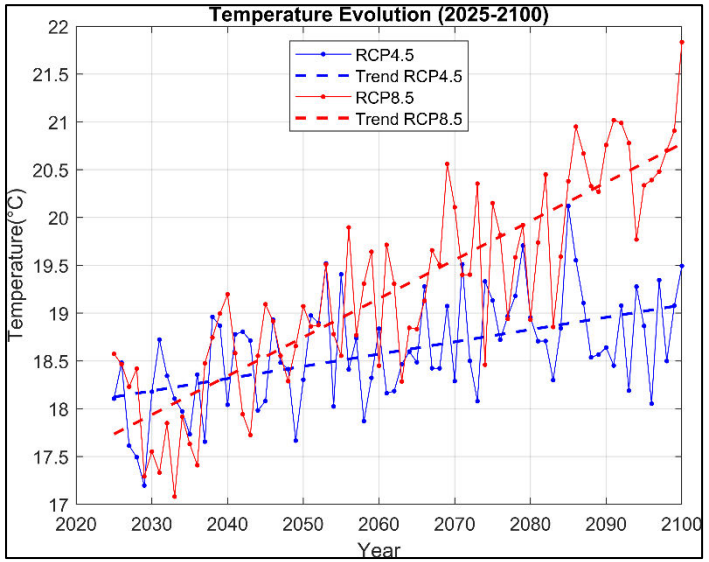
Sidi Slimane

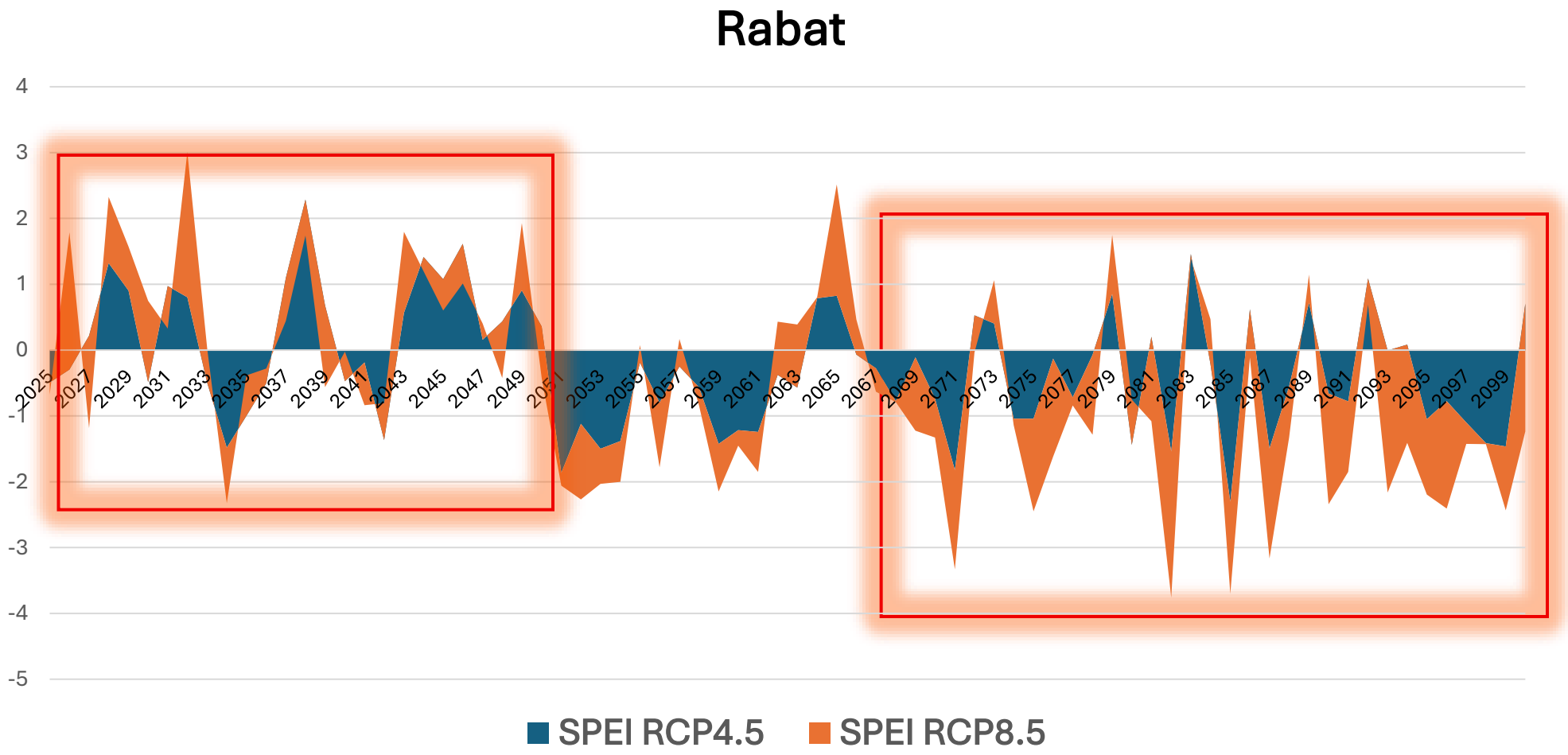


Sidi Yahya El Gharb



Tiflet




Rabat
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SPEI RCP4.5
SPEI RCP8.5

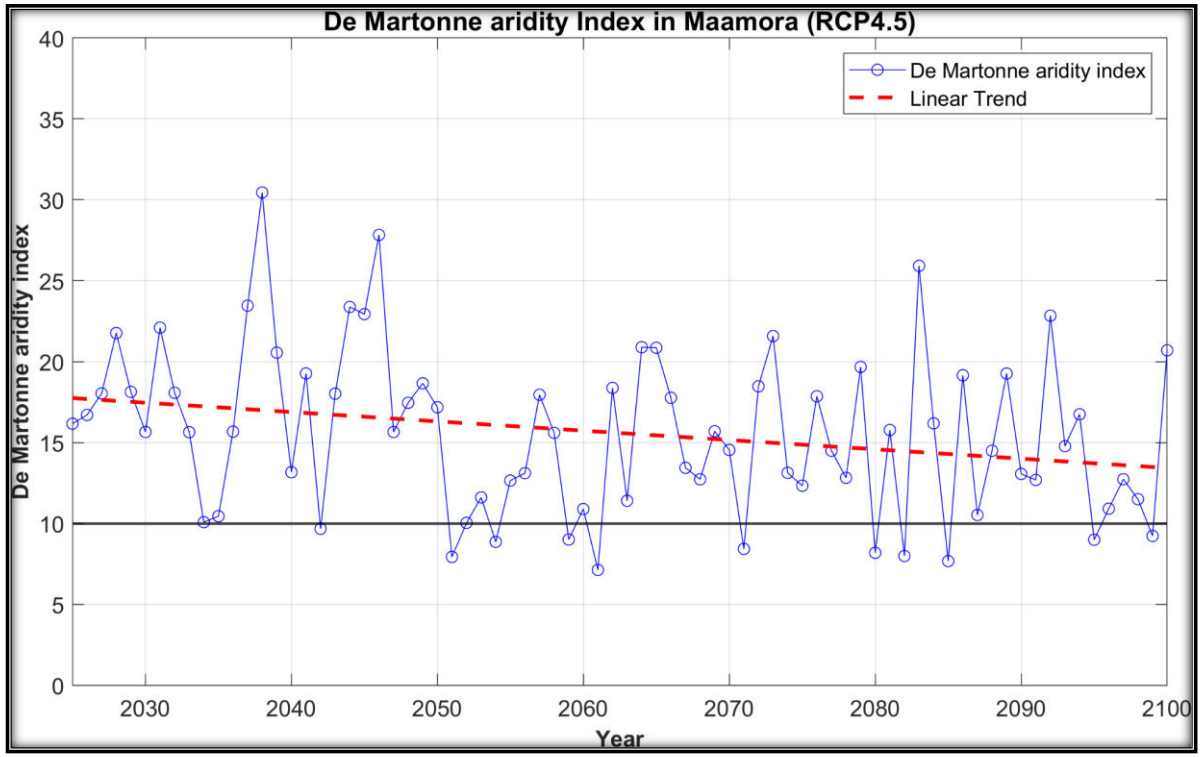
De Martonne Aridity Index

Formula :

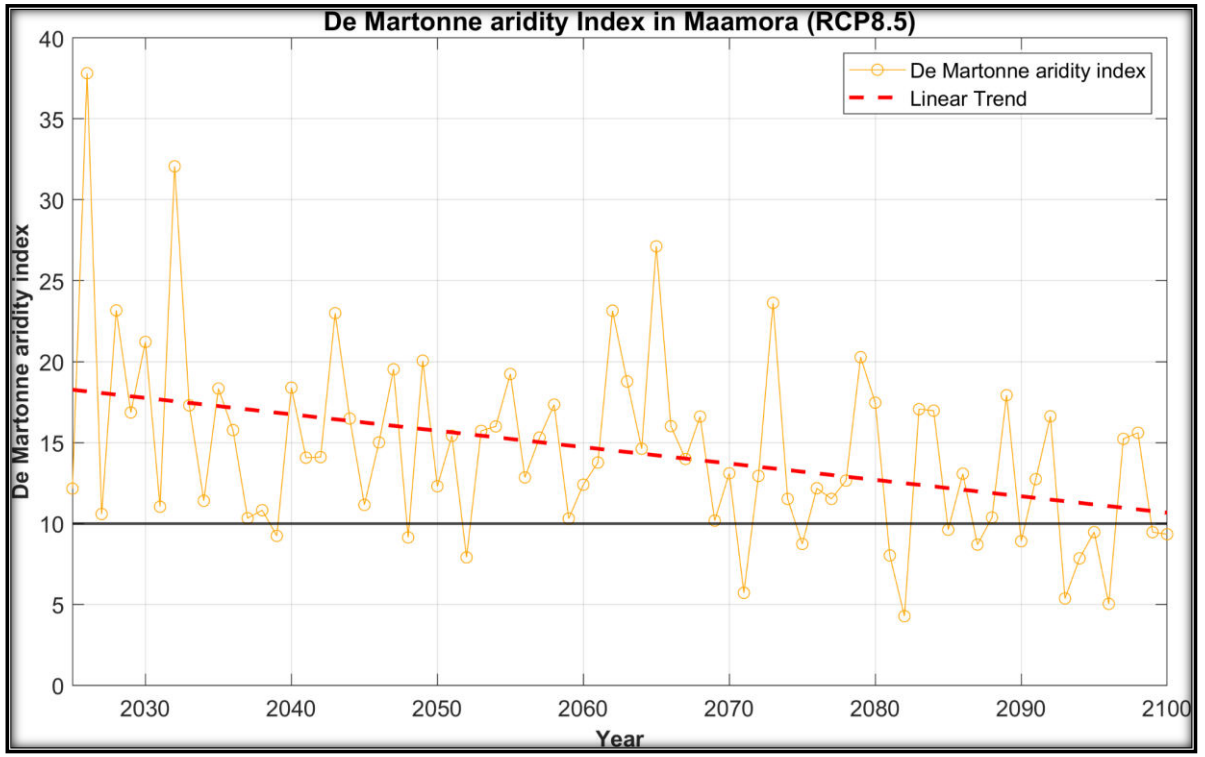
$$I_{\mathrm{DM}} = \frac{P}{T_a + 10}$$

Types of Climate	Values of Ia_{DM}
Arid	$Ia_{DM} < 10$
Semi-arid	$10 \leq Ia_{DM} < 20$
Mediterranean	$20 \leq Ia_{DM} < 24$
Semi-humid	$24 \leq Ia_{DM} < 28$
Humid	$28 \leq Ia_{DM} < 35$
Very humid	$35 \leq Ia_{DM} \leq 55$
Extremely humid	$Ia_{DM} > 55$

De Martonne Aridity Index



Average **2025-2049**	Average **2050-2074**	Average **2075-2100**
18.35793135	13.96934583	14.48013676

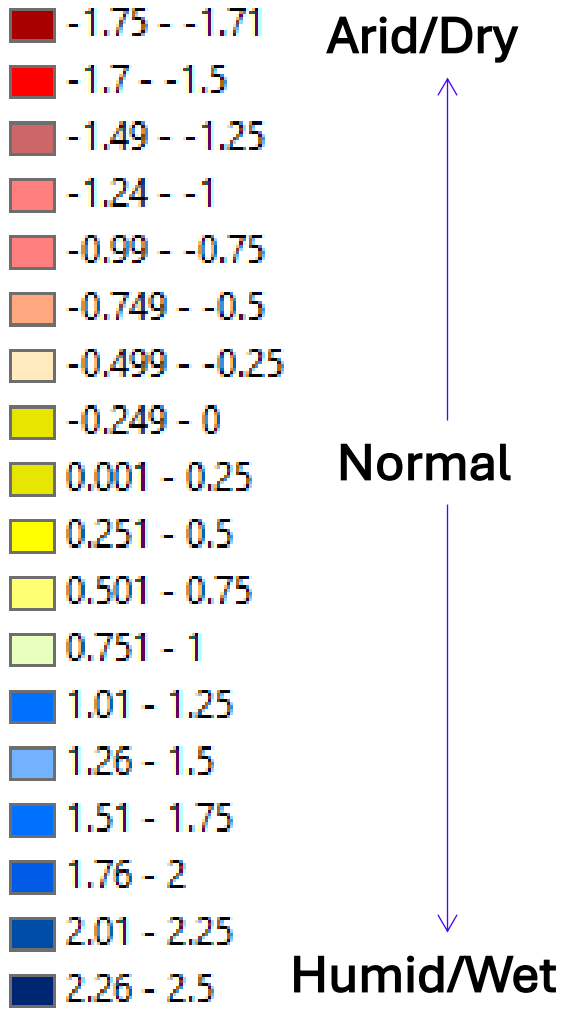


Average **2025-2049**	Average **2050-2074**	Average **2075-2100**
16.7585457	15.03319891	11.70669379

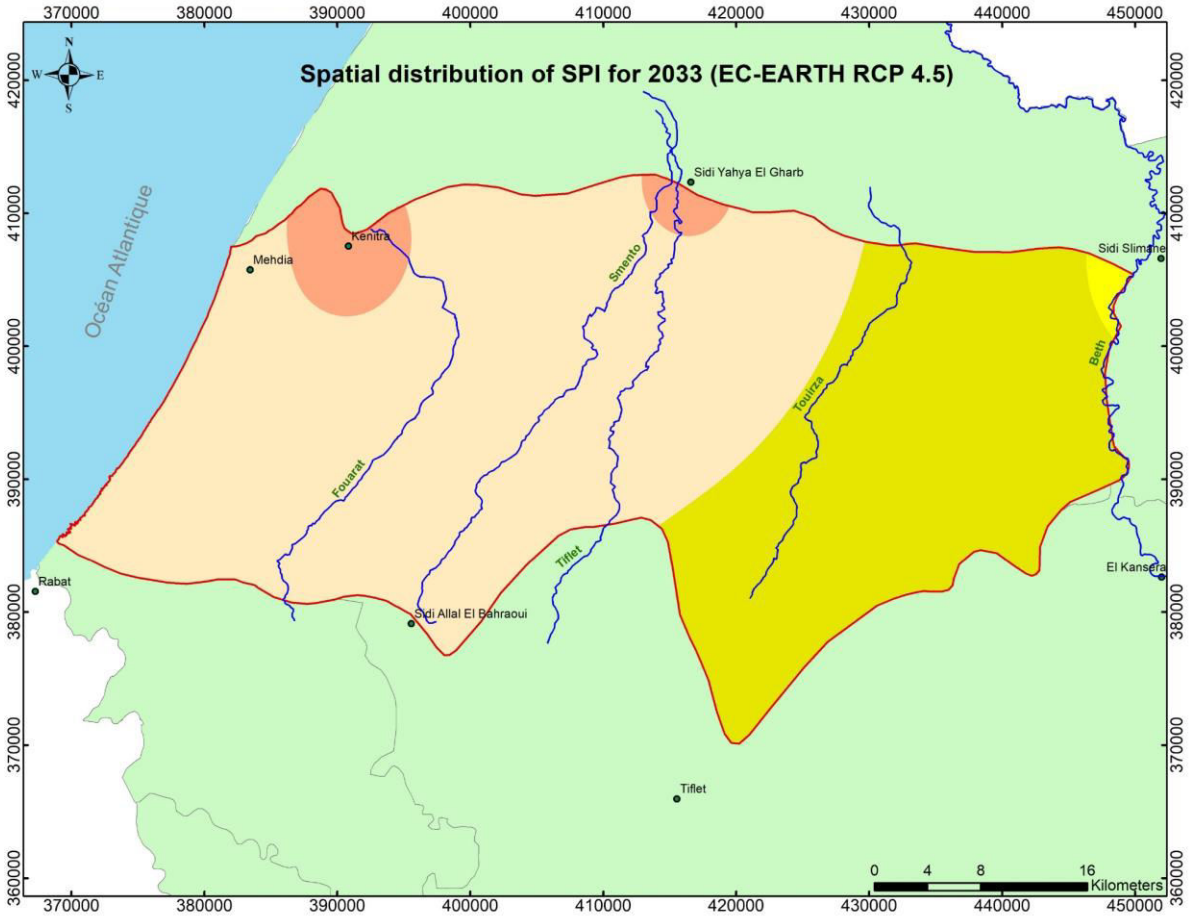
IV. Spatial Distribution of SPI and SPEI

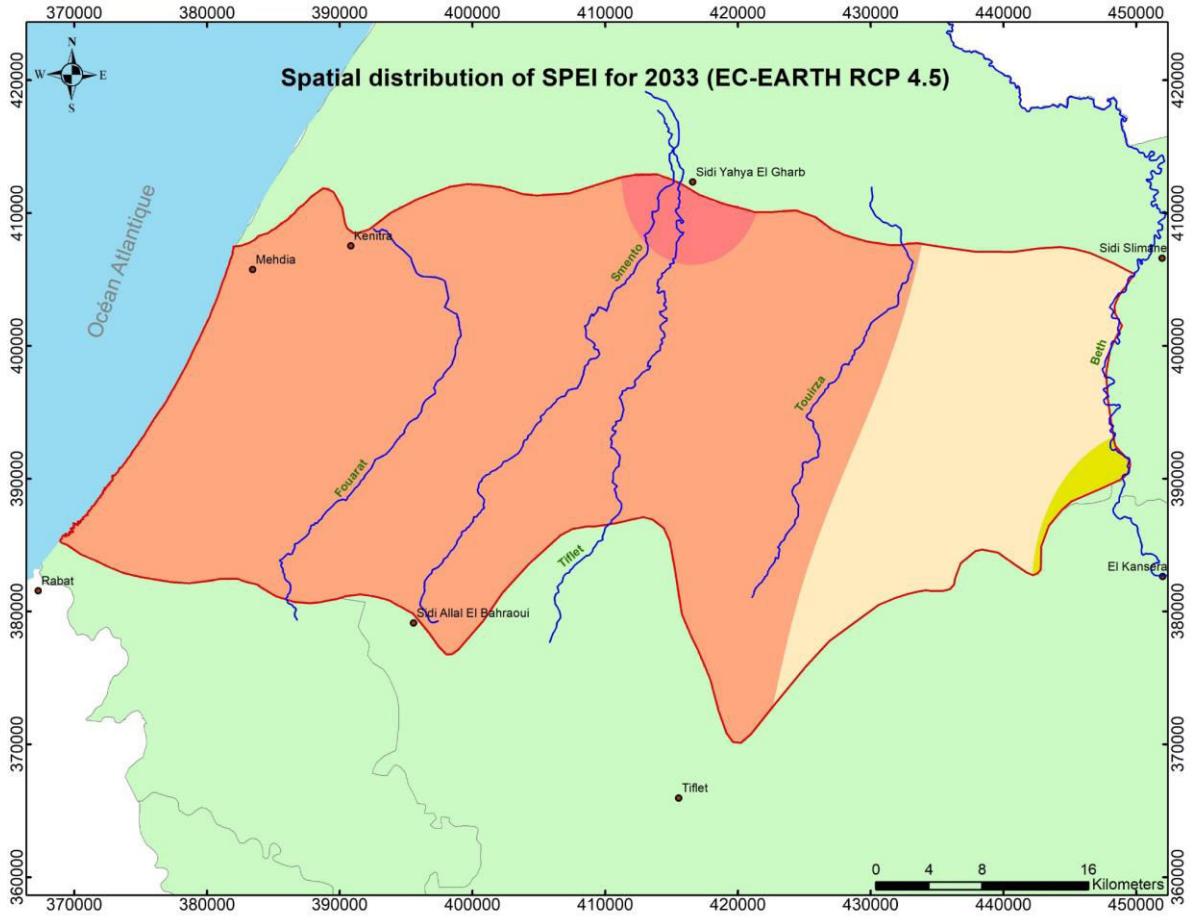
Spatial Distribution of SPI and SPEI

The Inverse Distance Weighting (IDW)



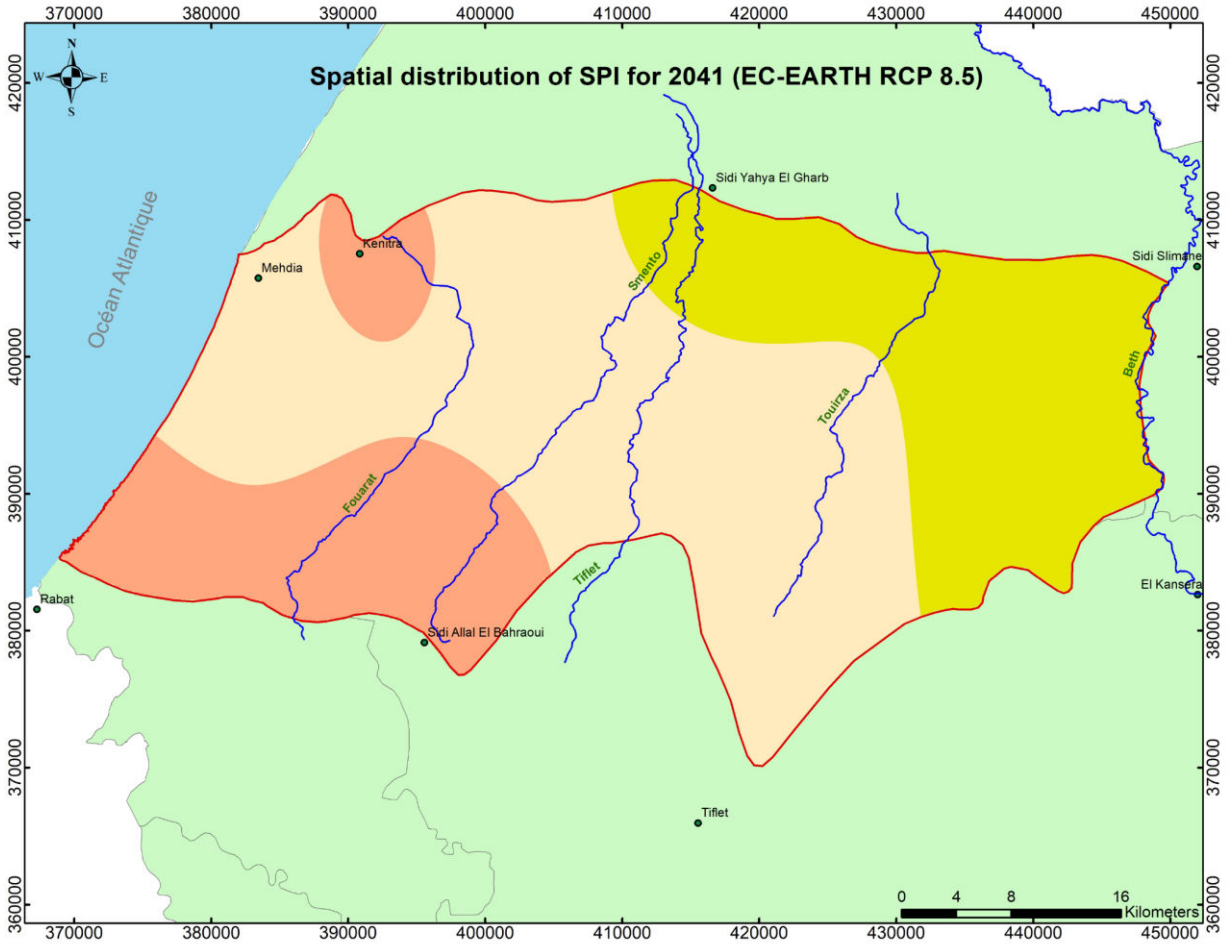
Spatial Distribution of SPI and SPEI

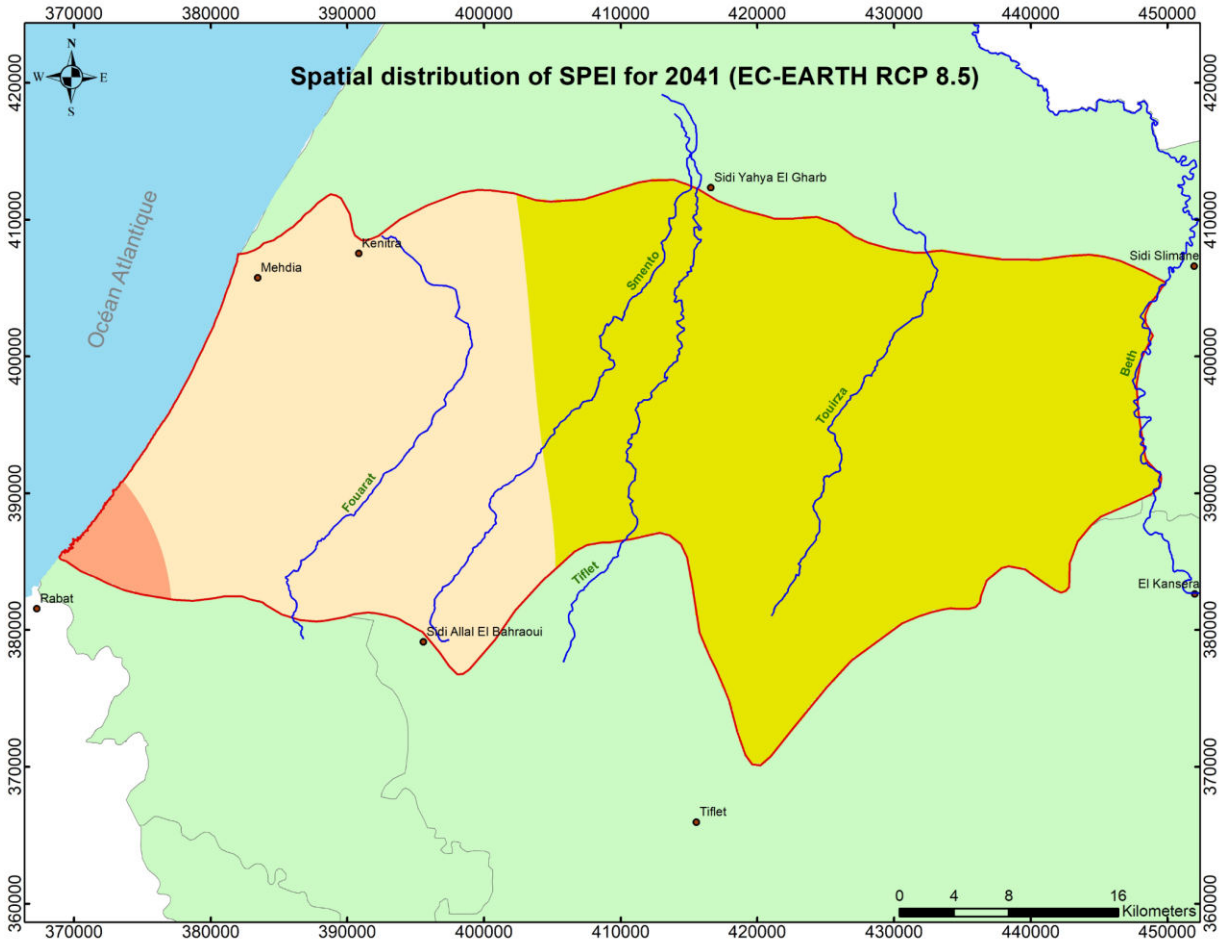




Spatial Distribution of SPI and SPEI for 2033 (RCP 4.5)

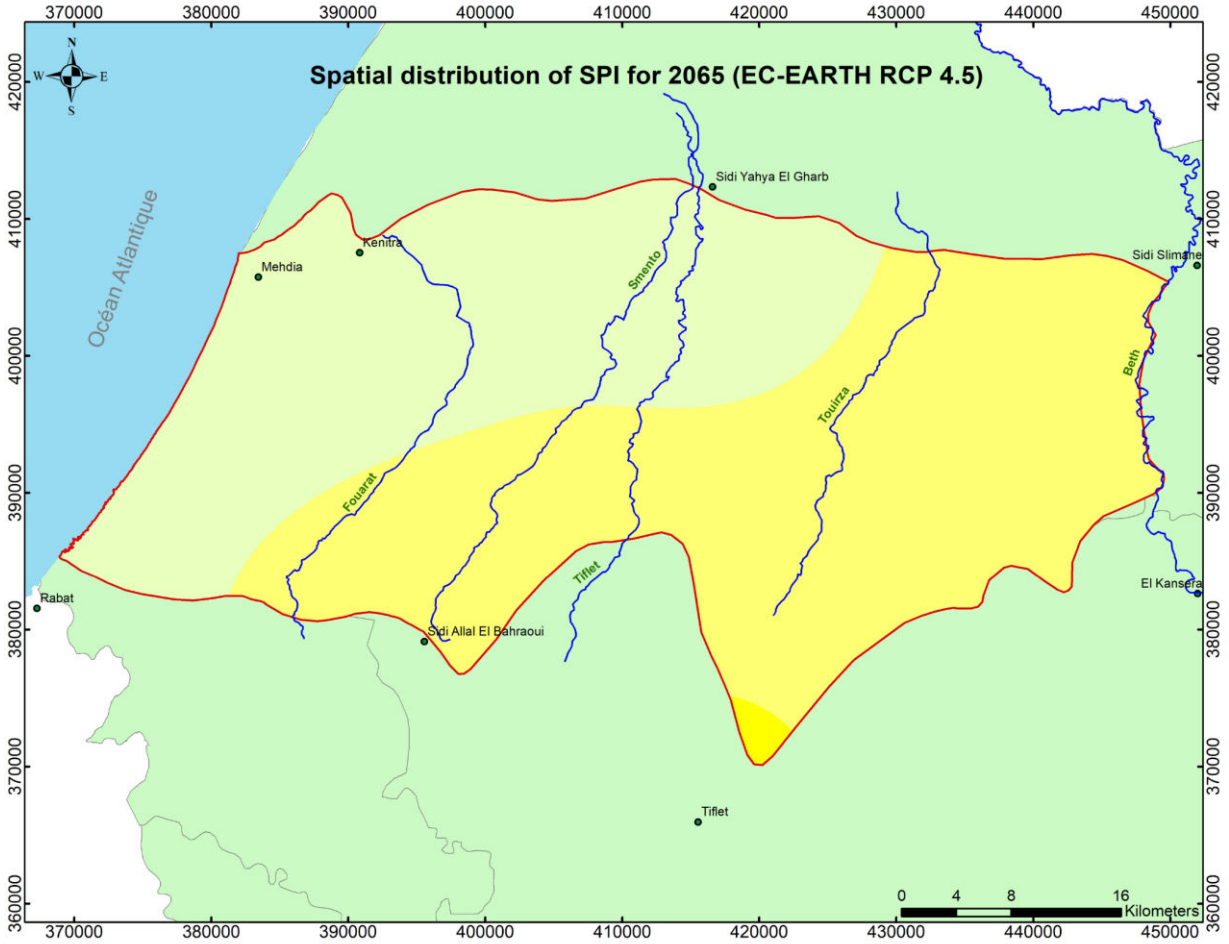
Spatial Distribution of SPI and SPEI

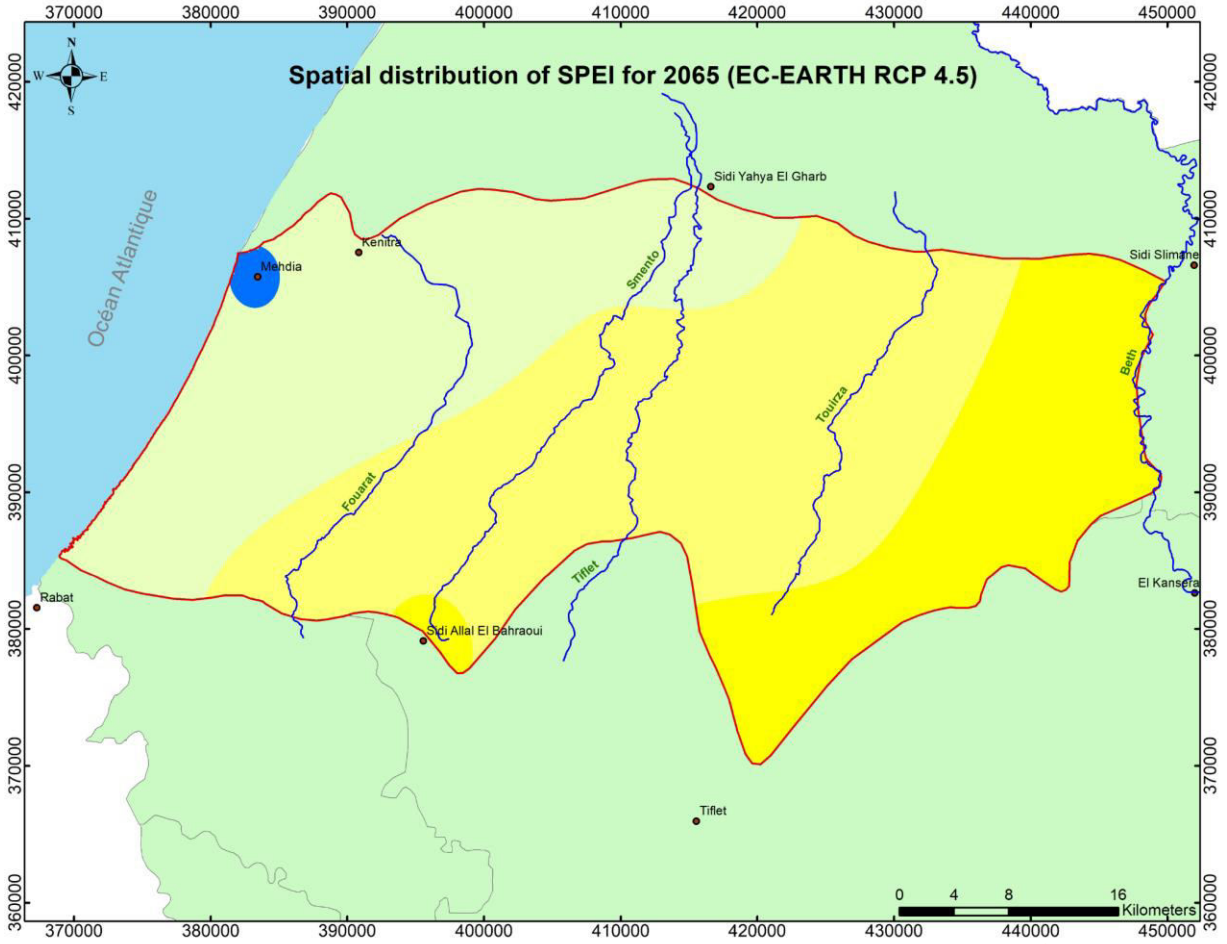




Spatial Distribution of SPI and SPEI for 2041 (RCP 8.5)

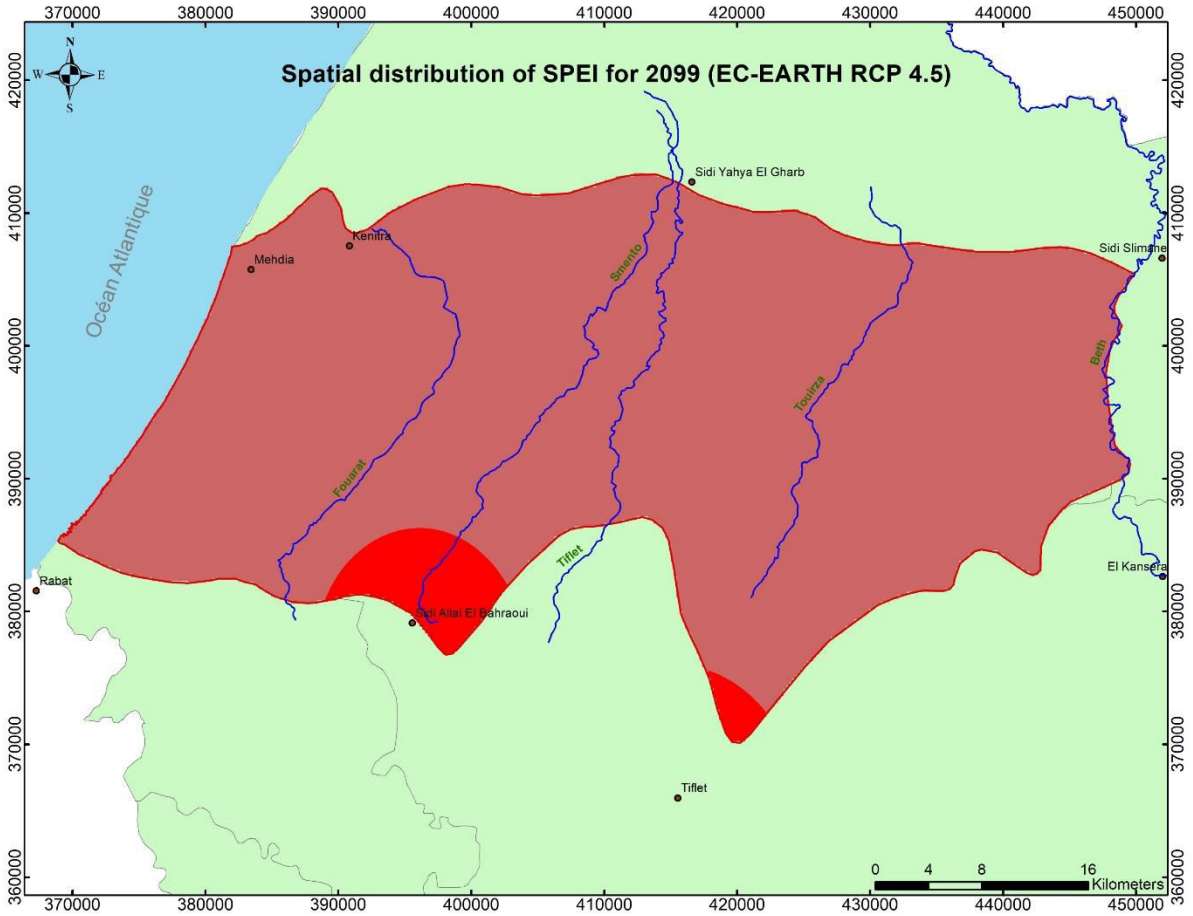
Spatial Distribution of SPI and SPEI

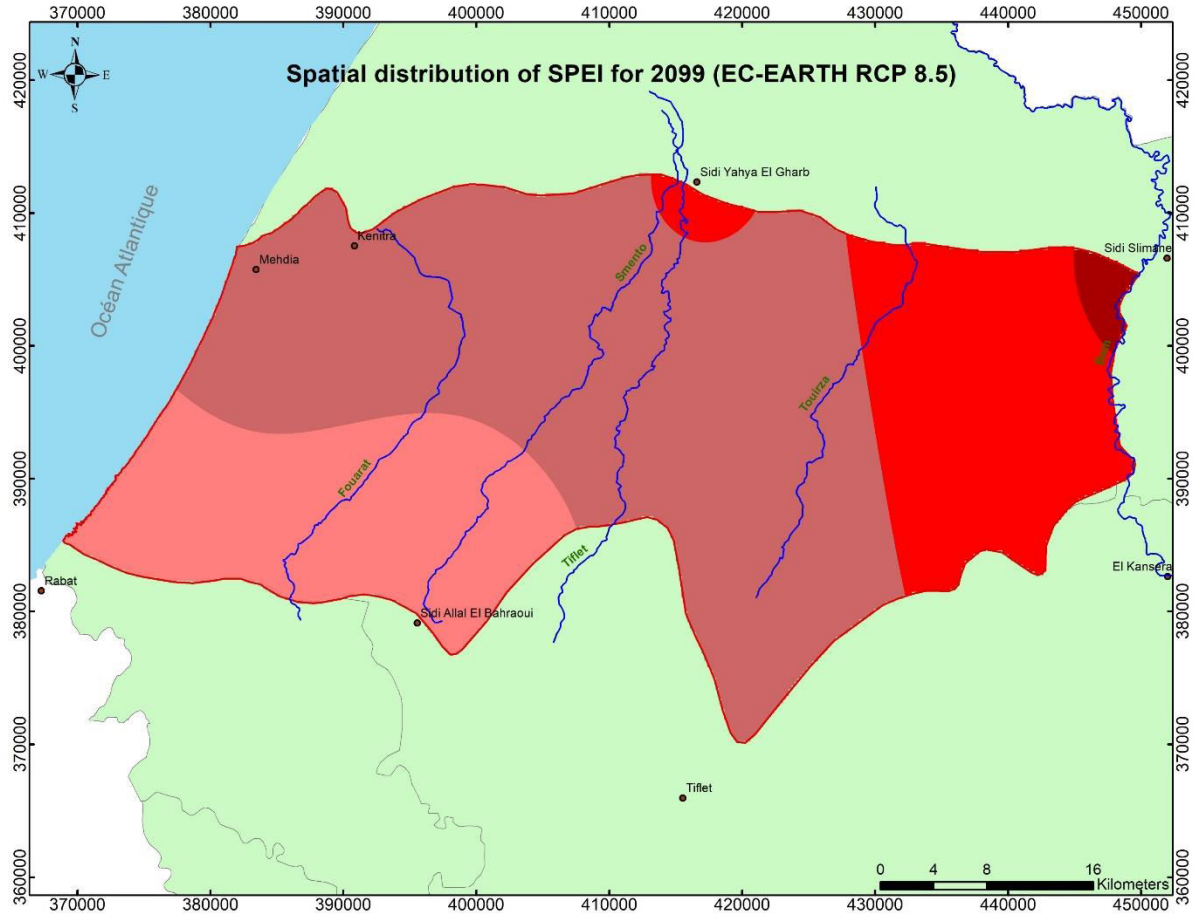




Spatial Distribution of SPI and SPEI for 2065 (RCP 4.5)

Spatial Distribution of SPI and SPEI





Spatial Distribution of SPEI for 2099 (RCP 4.5 and RCP 8.5)

V. Future Work

Future Work

- Choose more locations inside the limit to have a more detailed distribution of SPI and SPEI.
- Analyze changes and evolutions of these indices according to 5- or 10-year periods.
- Based on SPI-SPEI values, we're going to determine the recharge of our aquifer, which will serve as an input for the hydrogeological model.
- History of the SLR based on NASA data, and predict its evolution for the future.
- Impact of CC → Innovative solutions to protect and preserve water resources of the Maamora aquifer (especially against Seawater Intrusion).

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Marrakech, Morocco | 1 - 5 December 2025

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