Dynamic changes in the classification of water-energy regions over India

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Objective

Problem Statement

Study how the water and energy zones have transformed over the years in India. Visualize the spatial and temporal changes in the classification of water and energy zones and comment on the expansion and reduction of these zones with time.

Dataset

Multidimensional dataset of dimension 121x121x768 is given.

- We take spatial resolution of 0.25x0.25
- For latitude we have two extremes at 6.5^{D}N to 38.5^{D}N
- Thus total dimensions needed are (38.5-6.5)/0.25=129
- Similarly for longitudes we have extremes at 66.5^{D}E to 100^{D}E
- Thus total dimensions needed are (100-66.5)/0.25=135
- However we take only 121 dimensions for both of them
- Third dimension represents the time interval.
- Since we have monthly data of 64 years, it is of dimension (64X12)
- Thus we have dataset of dimension 121x121x768

Two data files given are:

1. PET_India.mat:- It contains information about potential evapotranspiration from soils plus transpiration by plants.
2. rain_India.mat:- It contains information about rainfall across various regions.

Introduction

Motivation

Water is an integral part of our lives which makes it essential for us to study its availability. Fresh water availability is important for assessing climate adaptation to ensure water and food security. Hence understanding the water balance components at global and continental level is of importance for a sustainable water resource management.

Assessment Methodology

Traditional assessment of available water is based on runoff, which necessitates rigorous hydrological models, simulations and observed measurements of streamflows. Simplistic and proxy to estimate water availability is based on the equation:

$$Precipitation(P) - Potential\ Evapotranspiration(PET)$$

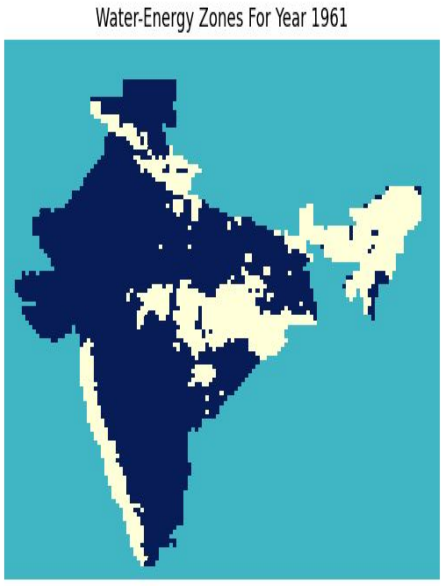
Apart from this we may also make use of the ratio PET/P commonly known as aridity index(ϕ). The threshold that represents the boundary between water-limited and energy-limited zones is used as 1. This ratio can also be used to differentiate regions into different zones based on the value of the ratio as follows:

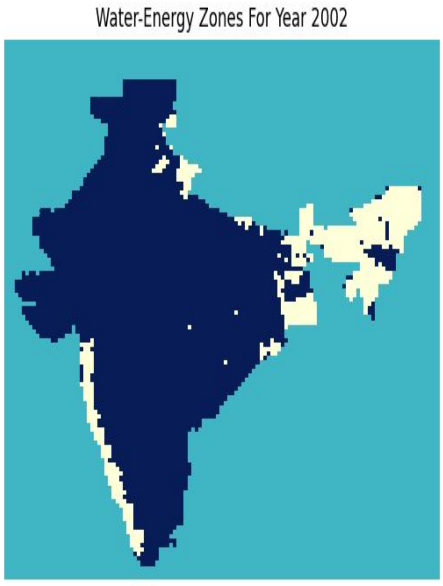
Regime	Classification
Arid	$12>\phi\geq5$
Semi-Arid	$5>\phi\geq2$
Sub-Humid	$2>\phi\geq0.75$
Humid	$0.75>\phi\geq0.375$

Analysis Method

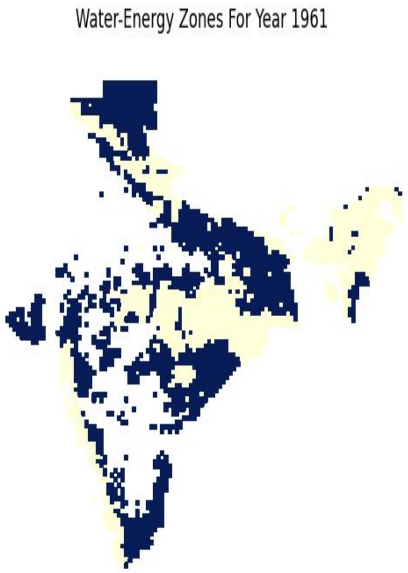
Initial Method

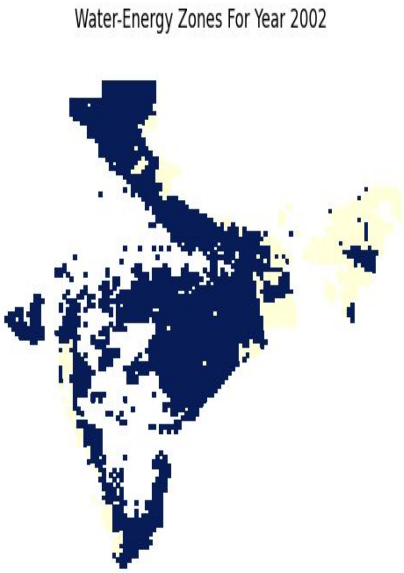
Initially we started to analyze data for the whole country. When we plotted water-energy zones, we could clearly observe the changing zones and map the outcomes to the prevailing climatic conditions of the country at that time. For example one can clearly differentiate between the zones in 1961 and in 2002.



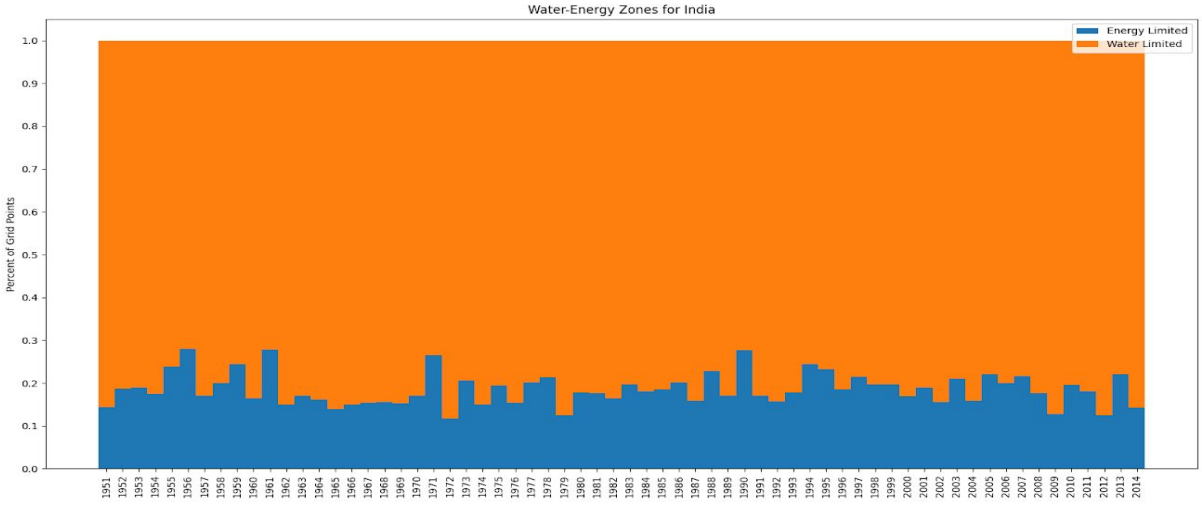


However some of the points didn't show any variation across 64 years and stayed the same which reduced the visible change obtained by applying various algorithms (say percent of change). So to counter that, we studied only those grid points which changed their zone at least once across the 64 years period. This helped to analyze the changes better as shown below.





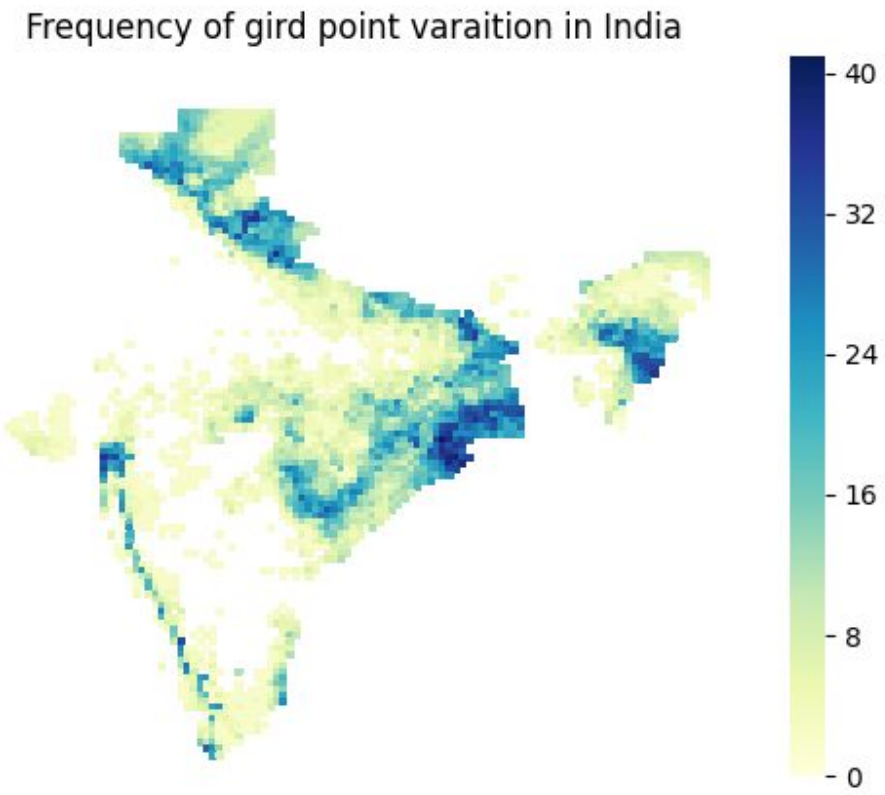
But when we carried out various experiments on the data, we could not get much information as some of the points changed from water-limited to energy-limited zone and others from energy-limited to water-limited zone (depending on the climate). For example the plots of water-limited zones show very less change across the years which contradicts other results obtained.

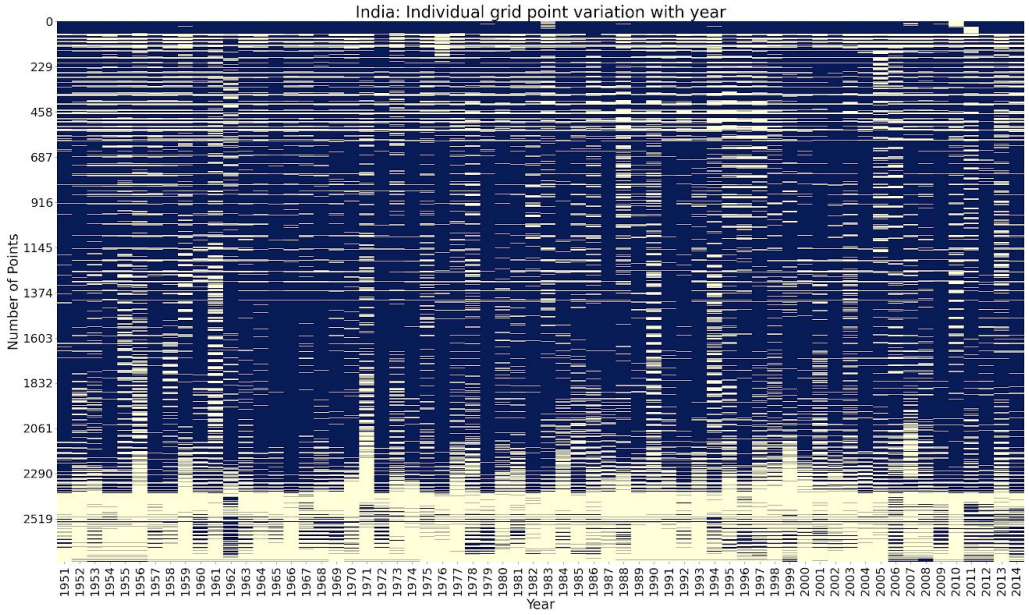


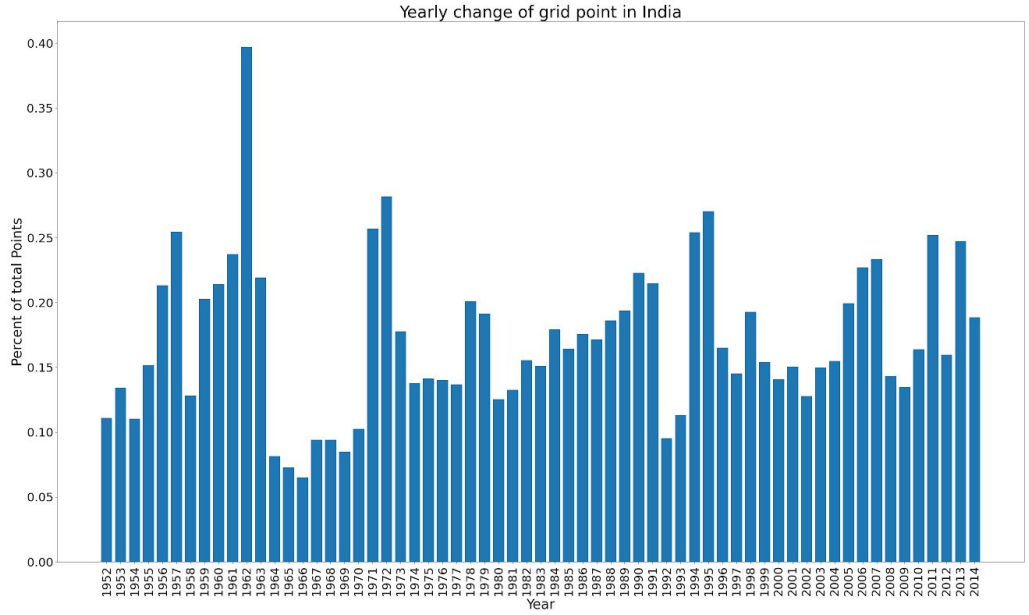
Also some of the results show much more relevance and are understood better on a small scale. Some of these results are:

- Frequency of grid point variation
- Individual grid point change across years
- Yearly change of number of grid points

These are shown below

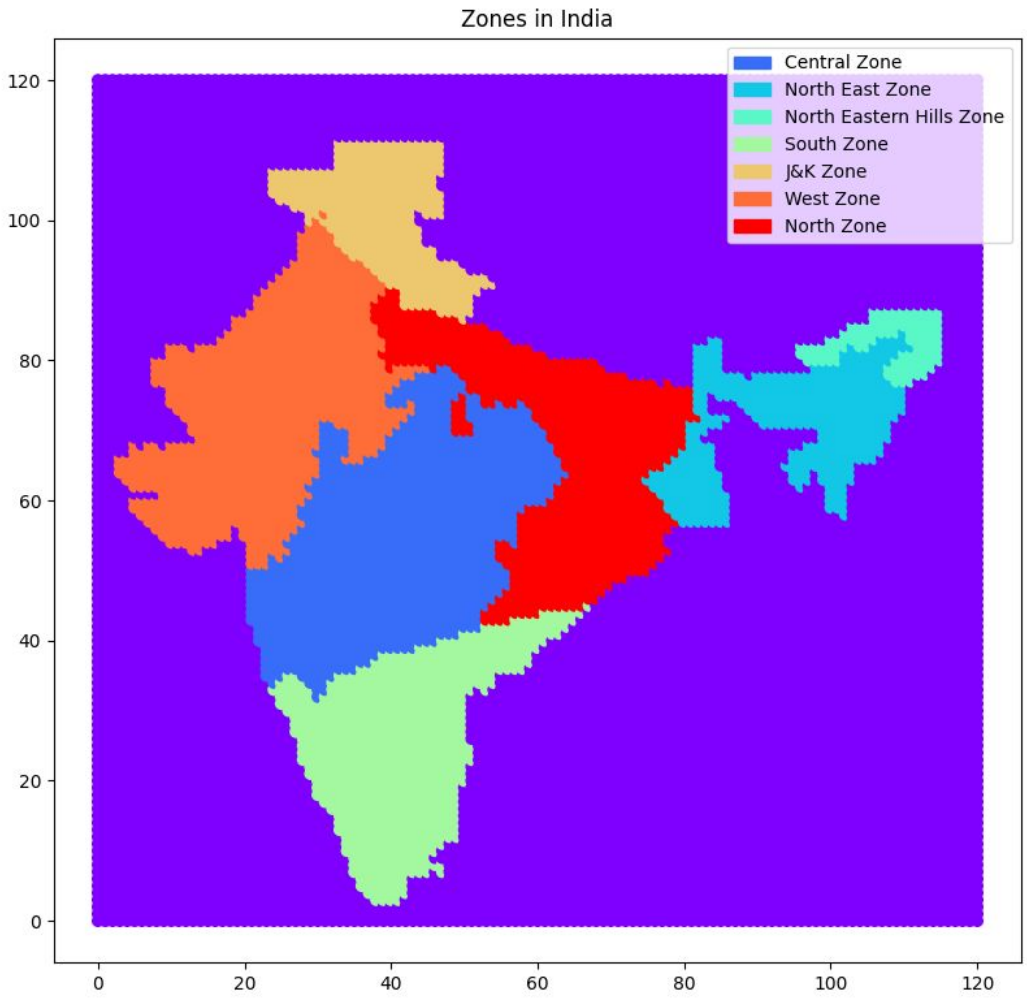



India: Individual grid point variation with year
Number of Points
Year


Yearly change of grid point in India
Percent of total Points
Year

Final Method

Thus to analyze better we carried out further analysis on zonal level. This helps us to combat factors like climate and other such factors which show differences in various parts of India. India is divided into 7 zones based on their geographical locations. Zonal analysis also helps us to compare and contrast two zones and visualize how one zone is different from other.



Basis of Analysis

As explained above, we first carried out our analysis on global data and then on zonal data as it gave better insight into the changes happening across the years. We have divide the analysis into two parts:-

1. Year based Analysis
    a. Water/energy limited zones in each year: This gives us an idea about the climatic conditions of a zone and tells us if it is predominantly water-limited or energy-limited.
    b. Percent of points which have changed zones in each year: This gives us an idea of how precipitation in a particular year might affect the water security of a zone.
2. Grid point based Analysis
    a. Yearly variation of zone of each grid point: This gives us an idea of water availability of an individual grid point.
    b. Number of times a grid point changes zones: This gives us an idea of how consistent the water-security of a zone is.

Apart from this, we have also done change point analysis (using Pettitt test) on the whole data set as well on the zonal data where we compare the average aridity before and after the change point. This analysis helps us to see how shift of zones occur across the years.

Results

Based on the above tests, we have compiled the following results for the dataset as a whole and based on individual zones.

- Variation of water energy zones across years
- Variation of water energy zones for changing points across years
- Water/energy zones
- Individual grid point variation across years
- Frequency of grid point variation
- Yearly change of grid points
- Change point analysis with before and after comparison

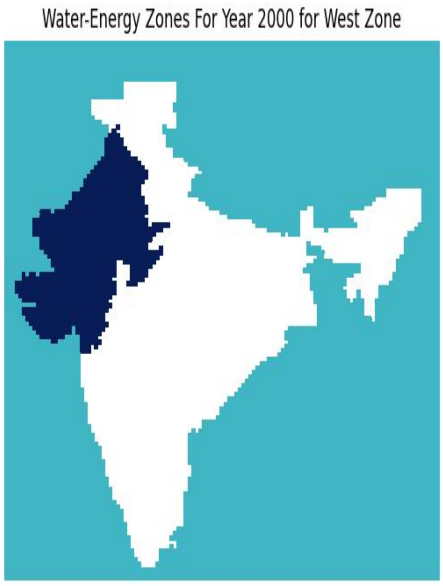
Using these we can compare any two zones with each other. We can also compare an individual zone with India and see the differences in water-security.

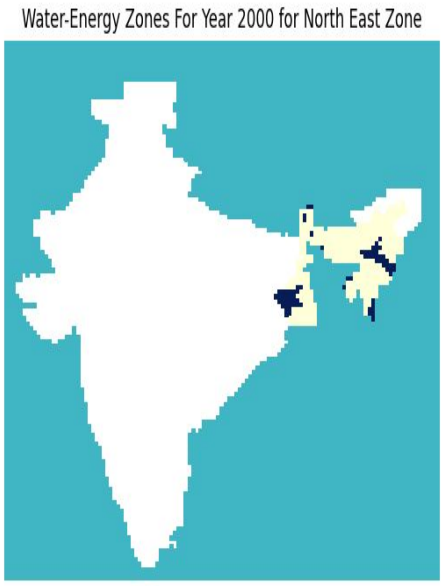
Comparison

For comparison purposes, we have compared the west zone and north east zone.

Predominant classification

As we can see West Zone is predominantly water-limited zone and North East Zone is predominantly energy-limited zone. This is also supported by the fact that the west zone is more of a desert area whereas the north east zone is a home to rainforests which receive heavy rainfall every year.

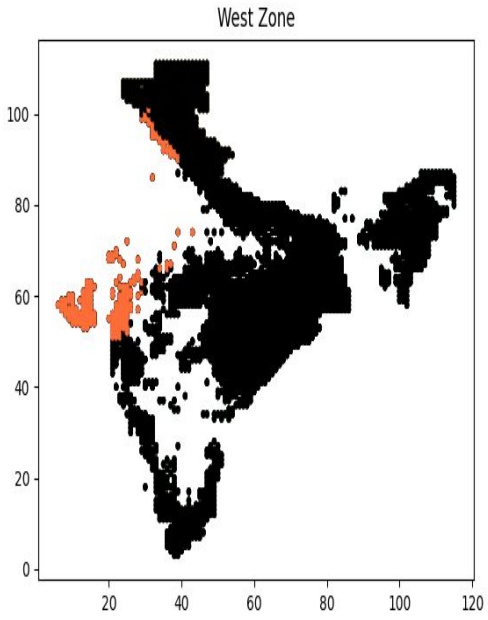


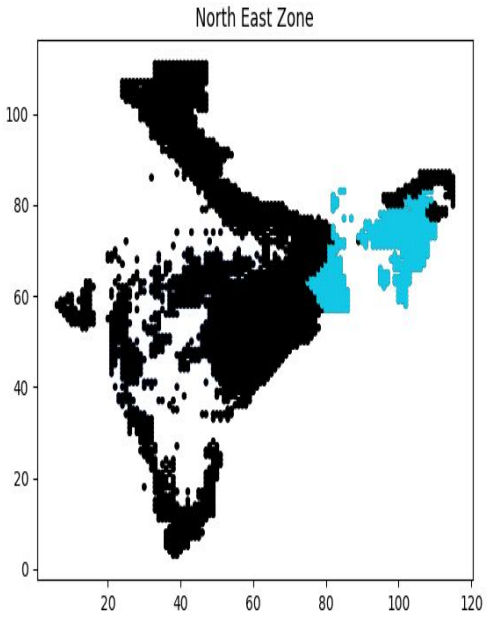


Changing Points

As seen below, most of the west zone remains water-limited across the years with very less variation. However north east zone is one of the most varied zones in India where points frequently change from water-limited to energy-limited

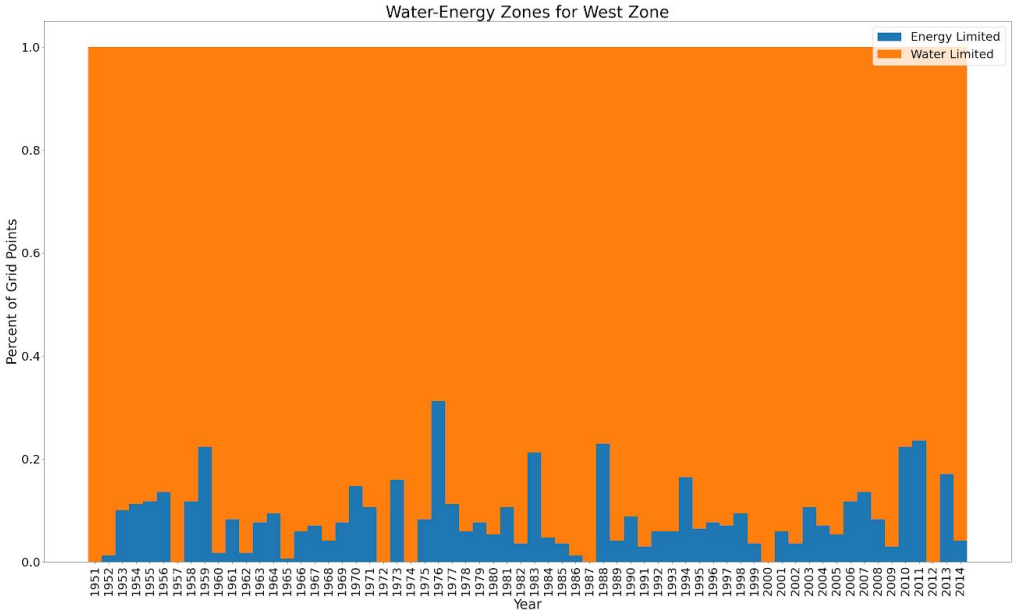
and vice versa. This is because due to heavy rainfall in one year, most of the points shift from water-limited to energy-limited zones.

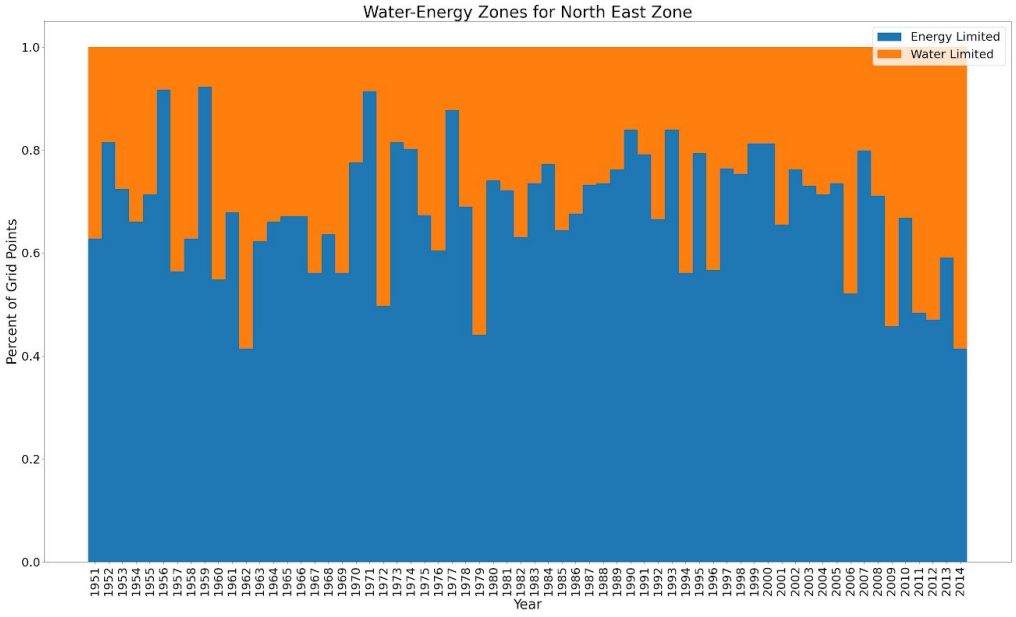




Combined Effect

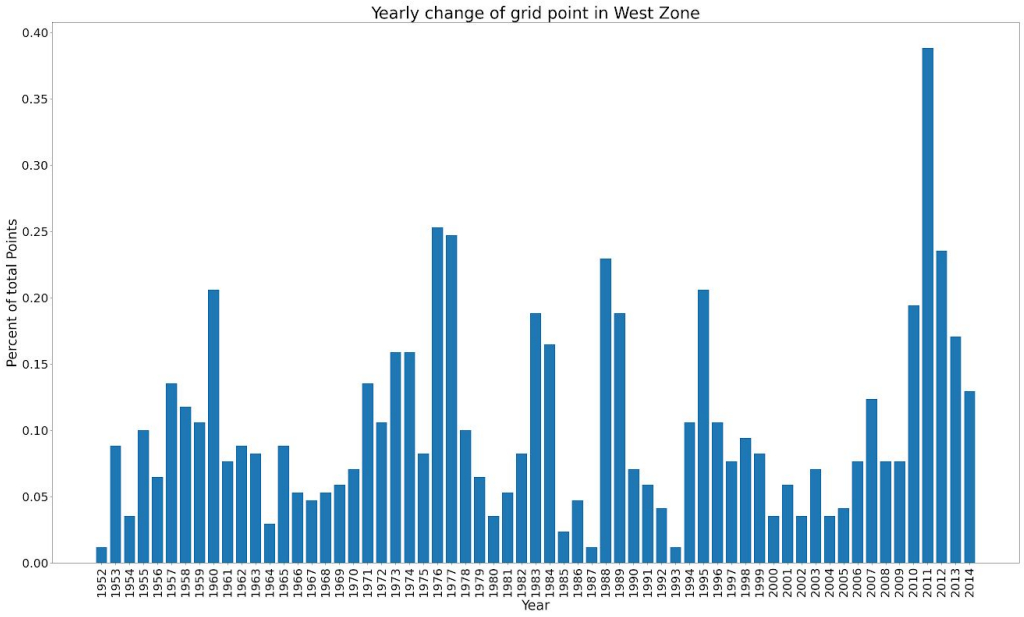
Both of the above points can be combined in the form of a bar chart and studied. From the below bar chart we can easily see that the west zone is a water-limited zone. Also there is not much variation across the years and most of the grid points do not change their zones. On the other hand, the north east zone is an energy-limited zone where individual grid points keep on changing from water to energy and vice versa. We can also note that due to huge rainforests, PET is also high which causes zones to shift from energy-limited to water-limited. West zone, mainly being a desert area with warm climate, does not have much vegetation and hence variation is also less.

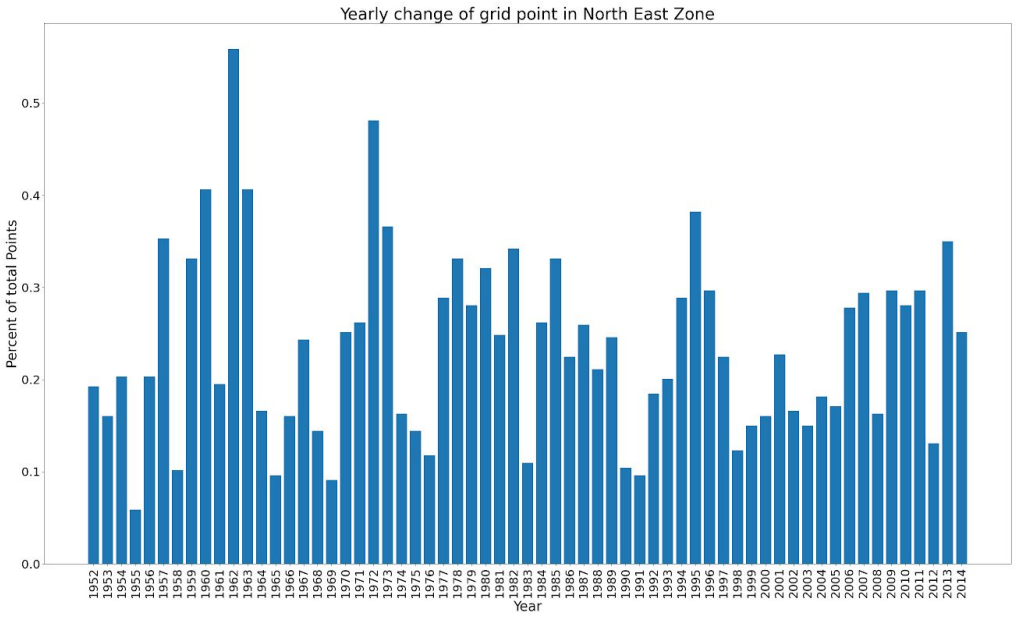




Yearly change of grid points

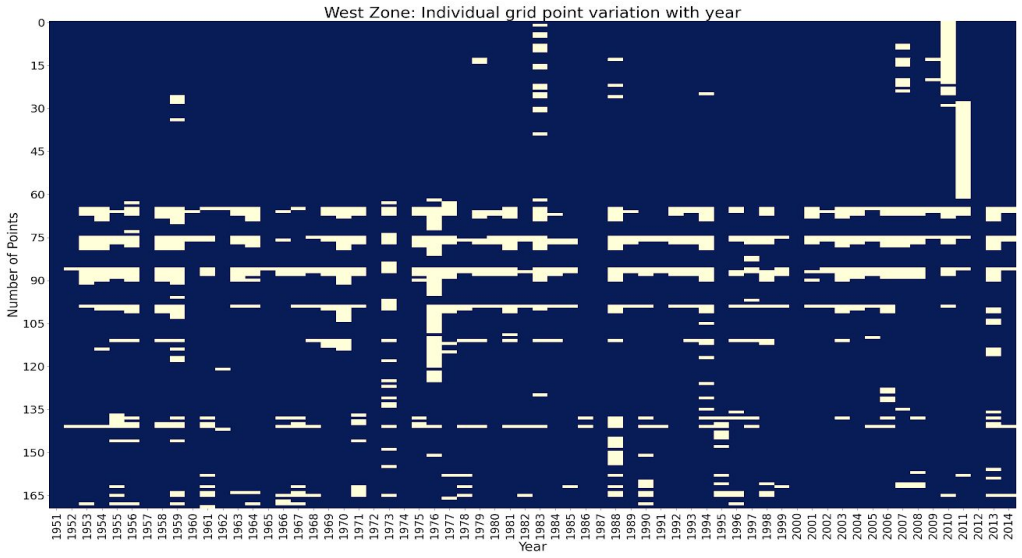
On an average about 10% of total points change their zones in the west zone whereas in the north east zone about 25% of points change their zones.

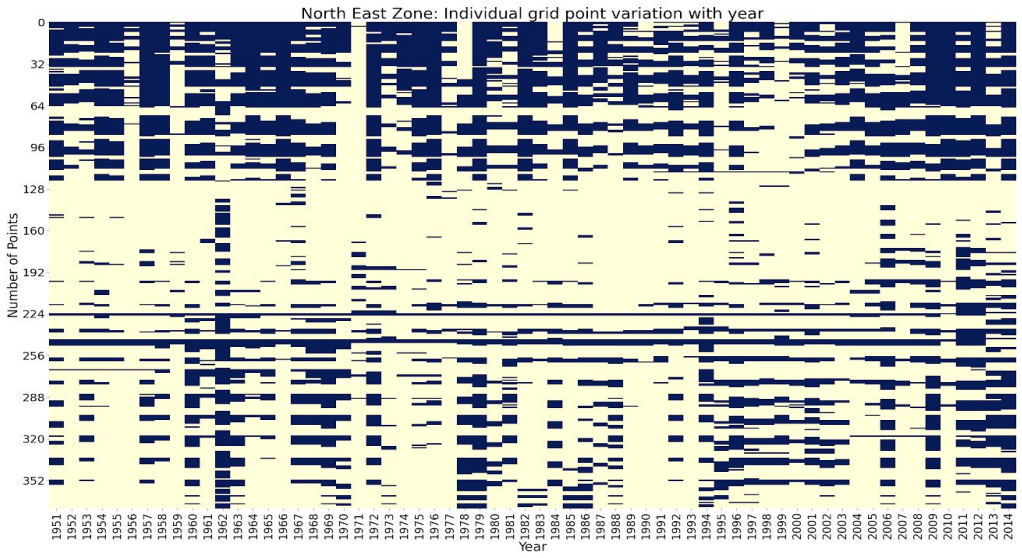




Individual grid point variation

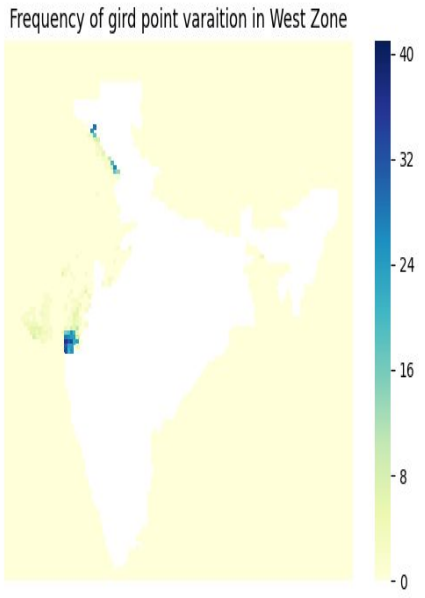
Below plots show that in the west zone only a small number of points are changing and that too they do not vary much across years. Whereas in the north east zone much more points change and that too more frequently.

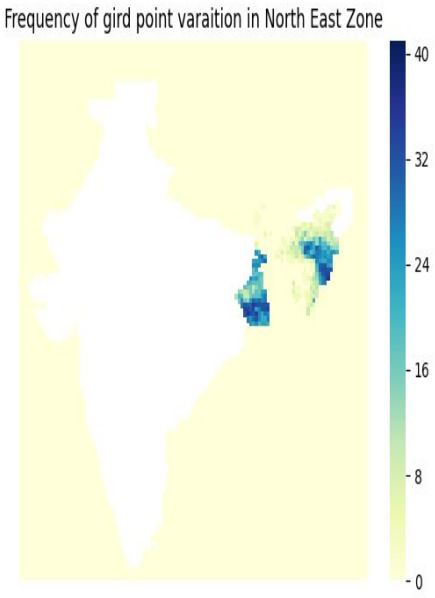




Frequency of Variation

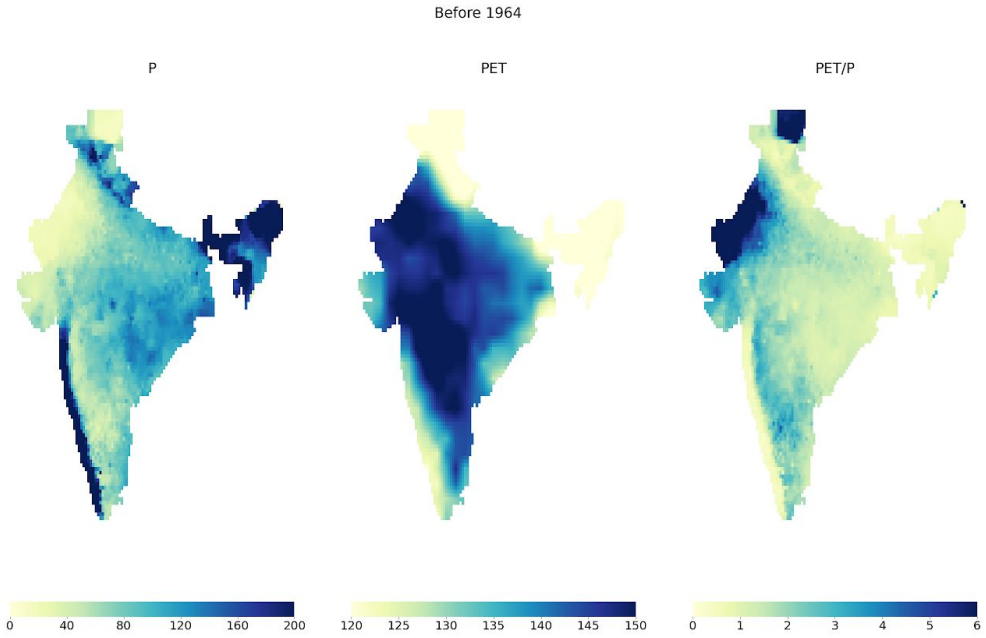
We can observe from below plots that most of the west zone does not change much across 64 years whereas the north east zone keeps on changing from water-limited to energy-limited zone.

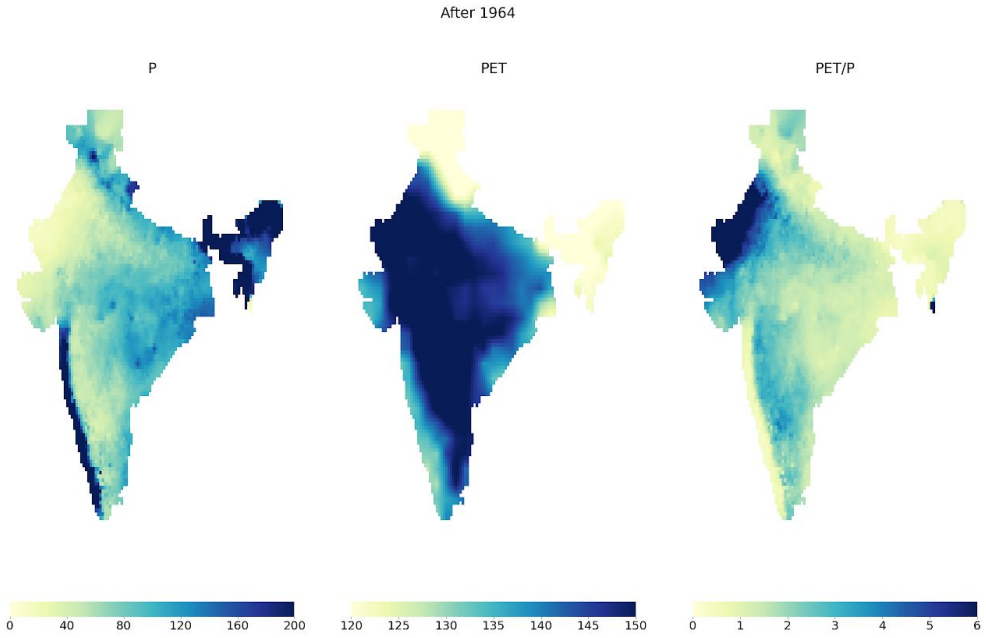




Change point Analysis

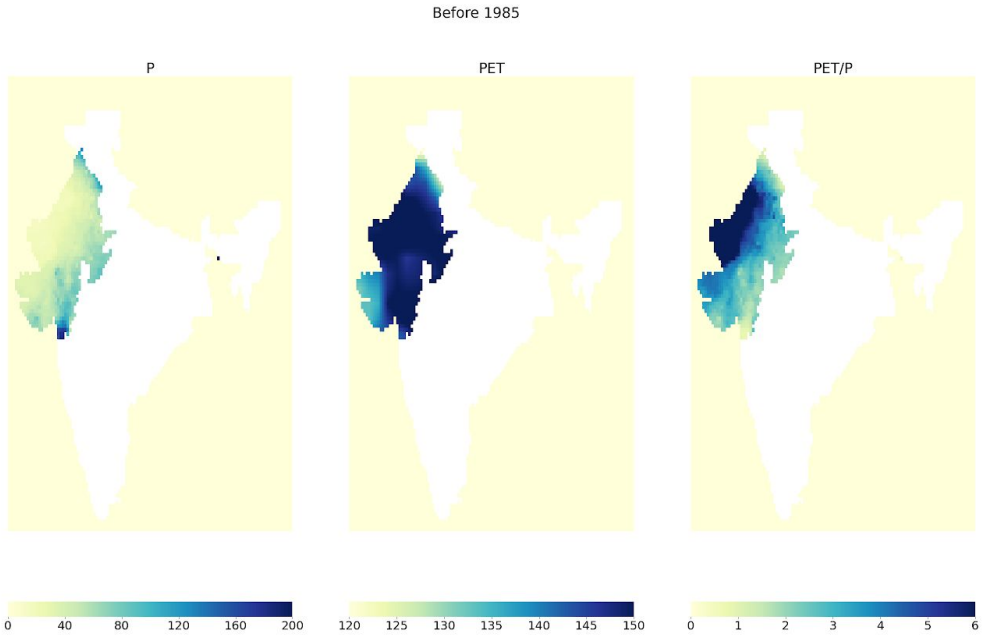
Initially we carried out change point analysis using the Pettitt test on the whole dataset where we obtained a change point at the year 1964. We then compared the aridity before and after 1964 to capture how the zones are changing. As observed from the figures, we can see that the north east zone remains as a energy limited zone only. Whereas for the west zone we can observe that PET has increased and P has decreased which results in high aridity as time progresses.

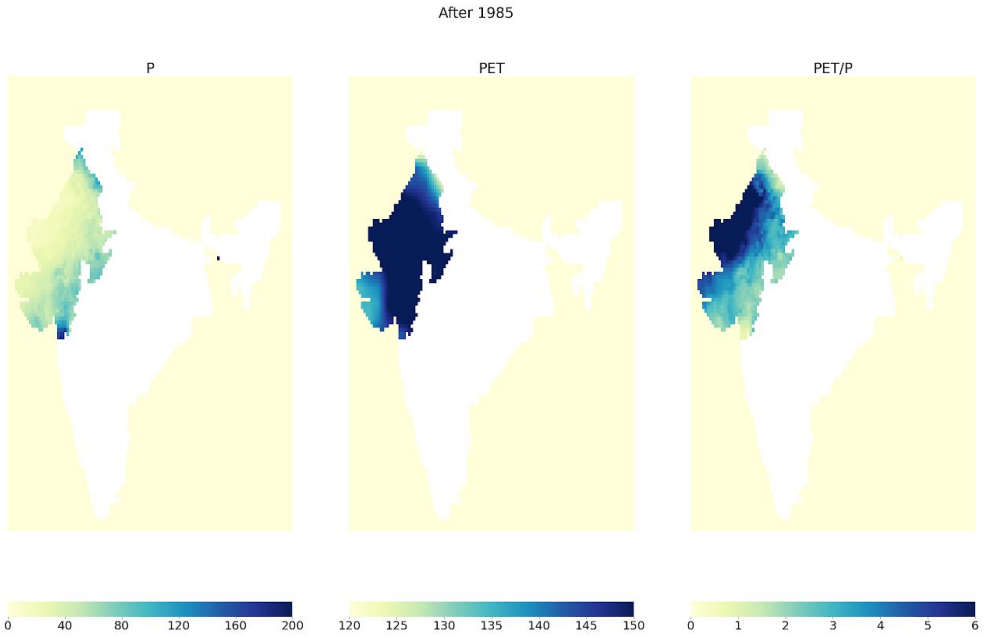

Before 1964
P
PET
PET/P
0 40 80 120 160 200
120 125 130 135 140 145 150
0 1 2 3 4 5 6

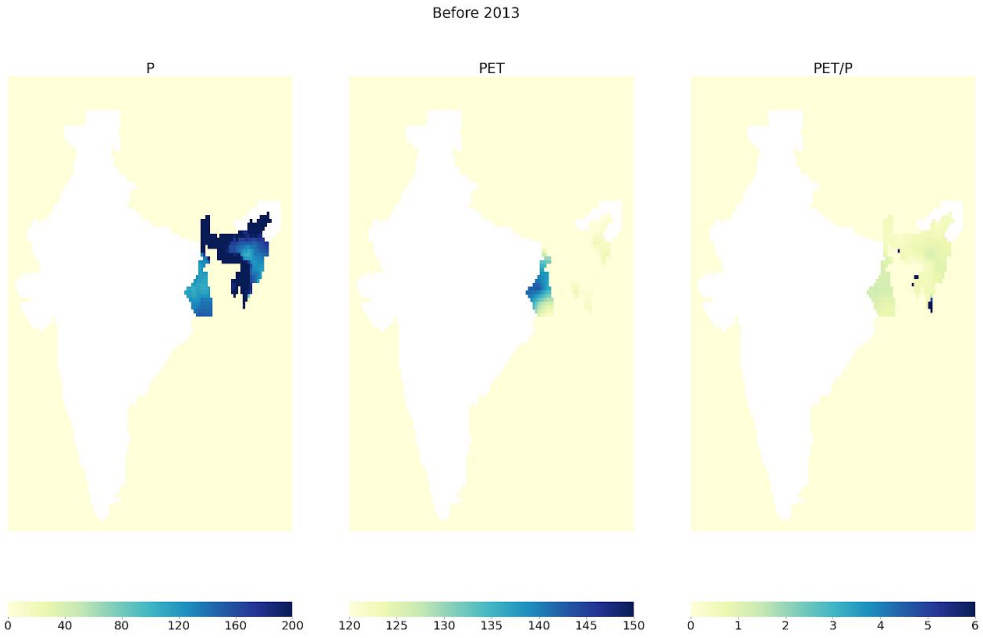

After 1964
P
PET
PET/P
0 40 80 120 160 200
120 125 130 135 140 145 150
0 1 2 3 4 5 6

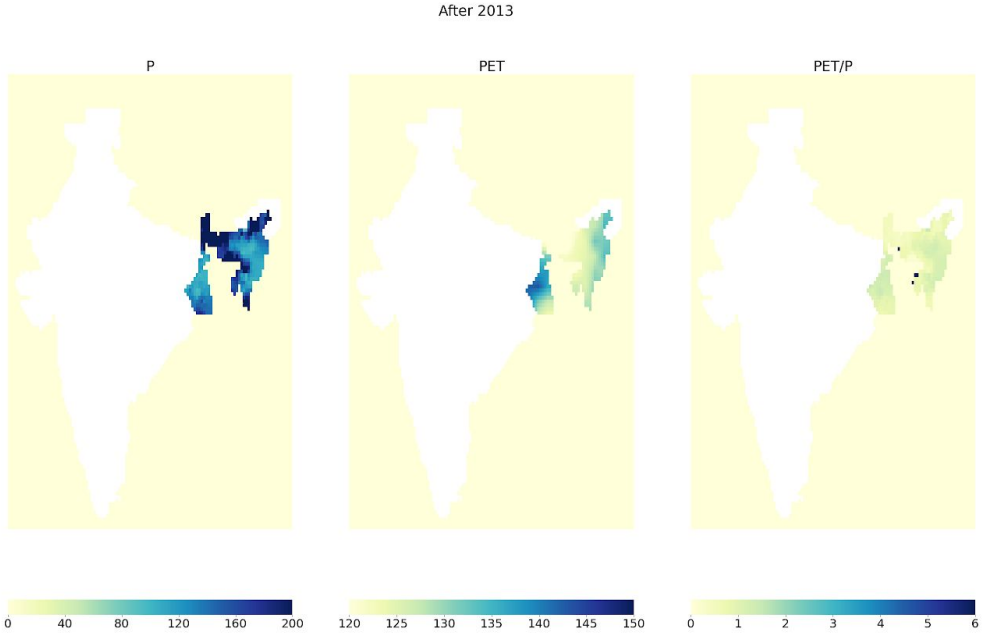
If we look specifically at the west zone, we observe that after 1985, PET has increased in the west zone which increases its aridity. Also a little bit decrease in rainfall is observed. Major changes are observed around the Thar desert. All this analysis indicates an expansion in the desert area which has accelerated lately due to human activities which have grown over the years causing rise in temperature.

On the other hand, the north east zone remains more or less energy-limited due to extensive rainfall. Lately decrease in rainfall is observed but overall its a predominant energy-limited zone.


Before 1985
P
PET
PET/P
0 40 80 120 160 200
120 125 130 135 140 145 150
0 1 2 3 4 5 6


After 1985
P
PET
PET/P
0 40 80 120 160 200
120 125 130 135 140 145 150
0 1 2 3 4 5 6


Before 2013
P
PET
PET/P
0 40 80 120 160 200
120 125 130 135 140 145 150
0 1 2 3 4 5 6


After 2013
P
PET
PET/P
0 40 80 120 160 200
120 125 130 135 140 145 150
0 1 2 3 4 5 6