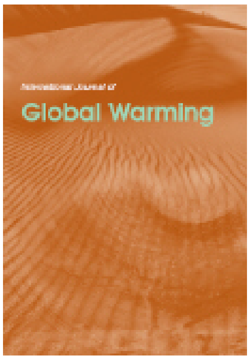

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Detection of annual rainfall trends using innovative trend analysis method in Benin

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Detection of annual rainfall trends using innovative trend analysis method in Benin

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Abstract: The planning and efficient management of water resources are an important subject in any development program. Thus, changes in rainfall patterns are among the major concerns in program design. This study assesses the evolution of rainfall trends on 11 stations that operated from 1922 to 2016. The classic Mann-Kendall method with Sen's slope and innovative trend analysis method of Şen are applied to annual rainfall at each station. The results show with the Mann-Kendall test that rainfall is decreasing at Bembereke, Natitingou, and Savè, and no change for the rest. With the ITA method, rainfall trends are noticed at ten stations, three are increasing, and seven decreasing. The three increasing stations are Adjohoun, Bopa, and Grand-Popo. The only station with no trend is Abomey. With the graphical analysis proposed by the ITA method, the low, medium, and high classes show trends that vary from one station to another.

Keywords: climate change; trend; innovative trend analysis; rainfall; Benin; Mann-Kendall.

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Biographical notes: Hilaire Kougbeagbede is a PhD in Atmospheric Physics at the Université d'Abomey-Calavi (Benin). His work focuses on climate analysis and the quantitative estimation of rainfall in West Africa.

1 Introduction

Climate significantly changes since the industrial era due to human activity (IPCC, 2021). This causes extreme weather events, such as heavy rains, heat waves, storms and droughts, which become more frequent and more powerful in many parts of the world (Bell et al., 2018; Knutson et al, 2018). These extreme weather events affect variety areas, from infrastructure to human health (Bell et al., 2018). The effects of climate change are felt most by communities that are sensitive to climate variability (Belova et al, 2022) or whose activities are highly sensitive to climate (Jain, 2017; Tamma, 2017; Hanigan and Chaston, 2022). Given the variety of effects and areas at risk, climate change is likely to increase communities' exposure to multiple risks (Bell et al., 2018). In Africa, for example, agriculture is subsistence and mostly depends on rainfall. Any change in rainfall affects yields and therefore food production. Climate change could also compromise people's health and safety, food and water security, and socioeconomic development, limiting their ability to cope and adapt (Shackleton and Luckert, 2015). And this can be supported by the State of the Climate in Africa 2021 report (WMO, 2022) which states that, for example, high water stress would affect around 250 million people and is expected to displace up to 700 million people by 2030. According to the same report, four out of five African countries are likely to lack sustainably managed water resources by 2030.

In West Africa, recent studies on rainfall trends show that annual rainfall of the first rainy season (April–July), shows a minor trend due to less frequent but more intense rainfall, mainly along the southern coast (Nkrumah et al., 2019). This precipitation may increase according to the sixth assessment report (IPCC, 2021). These changes are already affecting agriculture and the maritime economy in the subregion. The level of exposure and vulnerability of local people and property is increasing as a result of rising sea levels and coastal erosion. Across the region, these major risks will increase and could displace nearly 32 million people by 2050 (Rigaud et al., 2021).

The most important element of any study on climate change is to look for trends in the climate parameter, as it indicates on average whether the phenomenon is increasing or decreasing over time. Several works have been undertaken around the world to highlight trends through several methods, among which the most used are that of Mann-Kendall (Mann, 1975; Kendall, 1975) and its modifications (Hamed and Rao, 1998; Yue et al., 2002; Yue and Wang, 2004), Spearman rho (Spearman, 1904), linear regression (Edgell, 2002), the Theil-Sen slope (Theil, 1950; Sen, 1968), and recently the innovative trend analysis (ITA) method of Şen (2012, 2014). ITA is a flexible graphical method used in several domains and in different countries around the world (Mahmood et al., 2016; Şen, 2017; Caloiero, 2018; Gedefaw et al., 2018; Elouissi et al., 2016; Wu and Qian, 2017). It does not require prior assumptions about the distribution, the size of the series, and the internal correlation of the series. It also graphically highlights trends in sub-series. However, good water resources management requires not only the identification of trends over the whole series, but also over categories of values contained in the series. The magnitude of the change and the length of time over which the changes occur have significantly different implications for water resource planning and management. It is important to think of a deep analysis method that can highlight hidden trends using flexible graphical techniques.

In Benin, there is little work on trends, and it operates at different times. This does not facilitate convergence of results. For example, Gnanglè et al. (2011) show that annual precipitation over the period 1960–2008 is trending downwards by –5.5 mm/year, whereas that of Ahokpossi (2018) over the period 1940–2015 shows trends over only three stations. According to these results, annual rainfall is increasing at Parakou and decreasing at Kandi and Bohicon. Recently, Obada et al. (2018) from daily rain series from 1961 to 2016 showed that annual rainfall is decreasing. Of this work, no studies have yet used the ITA method of Şen (2012, 2014) to determine rainfall trends.

The present work aims to study the precipitation trend from historical data of Benin from 1922–2016 using the method of Mann-Kendall and ITA. The rest of the work is divided into two sections, the first describes the data and methods and the last one the results.

2 Data and methods

2.1 Study area and rainfall dataset

The Republic of Benin is located in West Africa (Figure 1). It borders Togo in the West, Nigeria in the East, Niger, and Burkina Faso in the North, and the Atlantic Ocean in the South. Its surface area is 114, 763 km^2, with a tree canopy at 65%. There are also clear forests and dense forests. Benin has a sub-equatorial climate in the south (with two dry seasons and two rainy seasons) and a Sudanese climate in the north (with a dry and rainy season). This West African climate system is characteristic of the alternation of the monsoon, the western wind coming from the ocean, and the northern trade winds marked by the Harmattan, the dry wind coming from the Sahara.

Figure 1 Location of Benin in West Africa and position of stations on the map of Benin

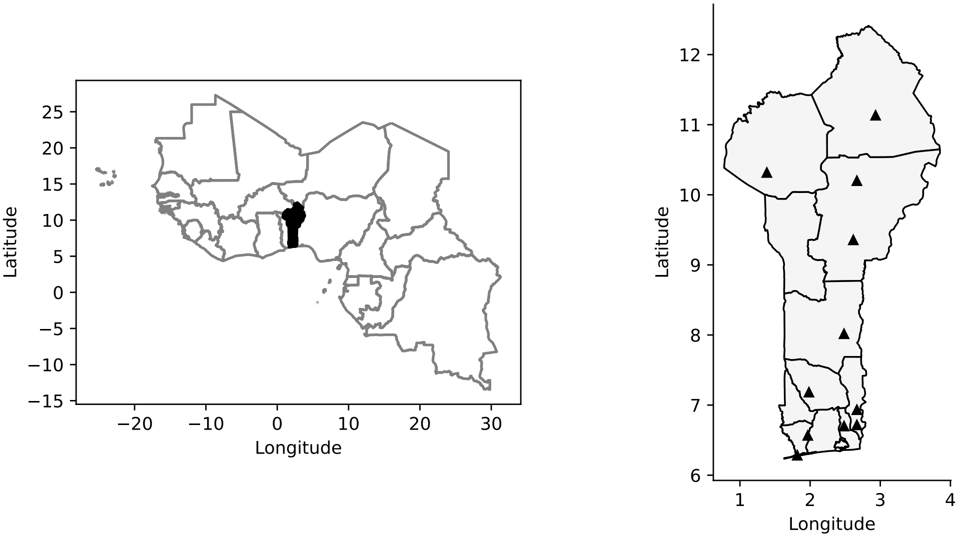


Table 1 geographical location of stations

Stations	*Longitude*	*Latitude*
ABOMEY	1.98333	7.18333
ADJOHOUN	2.48333	6.7
BOPA	1.96667	6.56667
BEMBEREKE	2.66667	10.2
GRAND-POPO	1.81667	6.28333
KANDI	2.9333	11.1333
NATITINGOU	1.38333	10.31667
POBE	2.66667	6.93333
PARAKOU	2.61543	9.35566
SAKETE	2.66667	6.71667
SAVE	2.48333	8.01667

Data used for this work are daily precipitation collected by Météo-Benin from 1922 to 2016. The selected stations are those with less than ten percent missing data and operating for at least 80 years. Thus, a total of 11 stations will be the subject of this study. The coordinates of these stations are presented in Table 1. Figure 1 shows their position on the map of Benin. On the basis of daily data, annual rainfall has been calculated. The methods described below are applied to the annual rainfall of each station.

2.2 Methods

2.2.1 Mann-Kendall trend test

Mann-Kendall (MK) test is often used to detect possible gradual changes in hydrological meteorological time series. According to Mann (1975) and Kendall (1975), this non-parametric rank-based test is used to determine whether the correlation between time and the study variable is significant or not. Let $x_1, x_2, \ldots, x_n$ be a sample of independent values relating to a X random variable whose stationarity is to be evaluated. The MK S statistic, MK $V(S)$ test variance and the standard normalised (Z) statistic are defined as follows (Mahmood et al., 2016):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} Sgn(x_j - x_k) \tag{1}$$

$$Sgn(x_j - x_k) = \begin{cases} +1, & \text{if } (x_j - x_k) > 0 \\ 0, & \text{if } (x_j - x_k) = 0 \\ -1, & \text{if } (x_j - x_k) < 0 \end{cases} \tag{2}$$

When $n \geq 10$, the S statistic is approximated by the normal distribution with average $E(S) = 0$ and variance:

$$Var(S) = \frac{[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)]}{18} \tag{3}$$

With t_p the number of times a group of identical p observations is encountered in a time series and q the largest number of observations included in a group of identical observations.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & \text{if } S < 0 \end{cases} \tag{4}$$

If Z >0, the trend is upward over time, and if $Z < 0$ the trend is downward. The significance of the test is evaluated with respect to a confidence interval. Thus, the null hypothesis H_0 (no trend) is rejected when the degree of significance (p-value) is greater than 5% in this work. In addition, when the trend is significant, the magnitude or slope ss of the time series is evaluated by a simple non-parametric procedure developed by Sen (1968). The slope of Sen (1968) is the median of all slopes calculated between each pair of points.

$$ss\ (\text{mm/an}) = median\left(\frac{x_j - x_k}{j - k}\right), \quad j > k \tag{5}$$

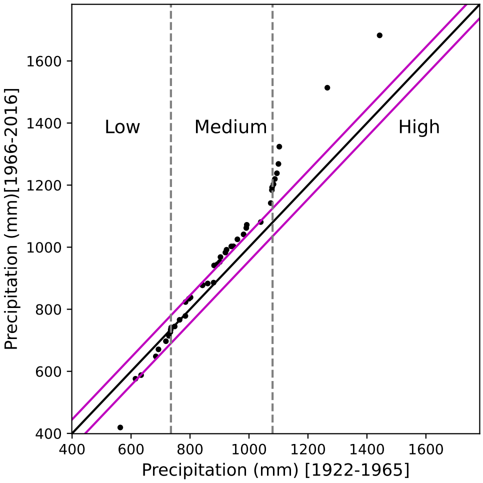
$$\begin{cases} ss > 0, & \text{upward trend} \\ ss < 0, & \text{downward trend} \end{cases}$$

With x_i and x_k the values of the series at time i and k respectively. $ss > 0$ indicates an upward trend in a time series. Otherwise, the dataset shows a downward trend over the study period.

2.2.2 Innovative trend analysis

The innovative trend analysis (ITA) method is a graphical method that allows the trend of a time series to be assessed graphically and by statistical analysis. It was introduced by Şen (2012). This method has been used to analyse the trend of several meteorological and hydrological series in Turkey (Şen, 2012, 2017), China (Wu and Qian, 2017), Algeria (Elouissi et al., 2016), Chad (Mahmood et al., 2016) and several other locations. ITA has great advantages over the MK test and other parametric and non-parametric statistical tests since it does not require assumptions such as nonlinearity, serial correlation and the number of samples.

Figure 2 Trend example (see online version for colours)



According to ITA method, the time series is divided into two equal numbers and the two sub-series are ordered separately in ascending order. To avoid the loss of the last data, the first observation is rejected if the time series size is odd. Based on the Cartesian coordinate system, the first sub-series (x) is placed on the X-axis and the second sub-series (y) is placed on the Y-axis. If the data points are on a 1:1 straight line (i.e. the two sub-series are equal), there is no trend. Data points above the 1:1 straight line shows an upward trend, and data points below that line shows a downward trend. A bound of 5% around 1:1 is defined to graphically assess the trend.

Elouissi et al. (2016) indicate that ITA allows for the detection of trends in the low, medium and high categories specifically based on the position of the data points. It is important to highlight that classification has important implications: for example, the trend of low rainfall will anticipate drought while the trend of high rainfall will allow flood management planning. Thus, in this study, three categories were defined according to percentiles: low (<20^e); medium (20^e–80^e); and high (>80^e). The different categories are separated by vertical dotted lines as shown in Figure 2.

Moreover, Şen (2014) defines the slope of the trend for ITA method as follow

$$p \text{ (mm/year)} = 2\left(\frac{\bar{y_2} - \bar{y_1}}{n}\right) \tag{6}$$

where $\bar{y_1}$ is the arithmetic mean of the first subseries and $\bar{y_2}$ is the arithmetic mean of the second subseries; n is the number of data points. Furthermore, Şen (2017) proposes to test the validity of the slope of the trend by defining a significance test at α level.

$$CL(1-\alpha) = 0 \pm s_{crit}\sigma_s \tag{7}$$

where α is the significance level, s_{cript} is the critical value of s and σ_s is the standard deviation of the s slope (see Şen, 2017 for details). In this study, the materiality threshold for α is 5%. When the values of the slope p are outside the confidence interval, the alternative hypothesis (Ha) is adopted. In this case, we can consider that there is a trend in the data analysed. The type of trend is given by the sign of the slope. A Positive value indicates that annual rainfall is increasing, if negative the trend type is decreasing and if the slope is 0 there is no trend. To avoid the loss of the last data, the first observation is rejected if the time series size is odd. In order to facilitate a comparison with the Mann-Kendall method, Wu and Qian (2017) define the trend index as below:

$$D = \frac{1}{n}\sum_{i=1}^{n}\frac{10(x_j - x_k)}{\bar{x}} \tag{8}$$

where D is the trend index, n is the size of the all series, x_j is the second half of the time series, x_k is the first half of the time series, n is the average of the first half of the time series. The positive (negative) value of the time series of the trend index represents an increasing (decreasing) trend. The trend index is multiplied by 10 to facilitate comparison on the same scale with results obtained from the Mann-Kendall trend (Wu and Qian, 2017).

3 Results and discussion

3.1 Spatio-temporal variation of precipitation

Figure 3 shows the boxplots of annual rainfall for each station. The box indicates the 25th, 50th and 75th percentile. The ends of the whiskers are calculated using 1.5 times the interquartile value.

The average rainfall on all stations varies between 900 mm and 1,300 mm. Among the stations in the south, the stations of Bopa and Grand-Popo are the least watered while Kandi is the least watered in the north. Natitingou is the wettest among the all. Natitingou is at the foot of the Atacora chain whose highest point in Benin is 658 metres and records a lot of orographic rain. Pobè, Kandi and Parakou stations did not record extreme values, while the rest of the stations did. Of this remainder, only Adjohoun has minimum and maximum extreme values. Savè has particular extremes, and this can be explained by the fact that this city is in the transition zone between the sub-equatorial climate and the Sudanian climate.

Figure 3 Boxplots of annual rainfall for the 11 studied stations (see online version for colours)

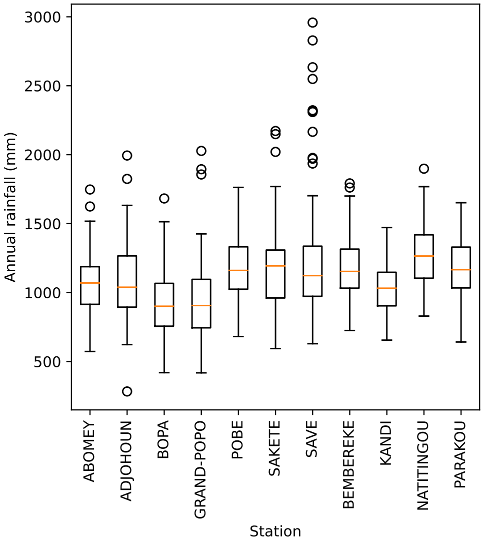


Table 2 Mann-Kendall test at 5% level

Stations	*Z*	*ss*	*p-value*	*Trend*
ABOMEY	0.386865	0.394	0.698856	No trend
ADJOHOUN	1.925869	2.072671	0.054121	No trend
BEMBEREKE	–3.450399	–3.075	0.00056	Decreasing
BOPA	1.870524	1.693994	0.061411	No trend
GRAND-POPO	1.877028	1.95	0.060514	No trend
KANDI	–0.594795	–0.385915	0.551981	No trend
NATITINGOU	–2.299479	–1.804762	0.021478	Decreasing
PARAKOU	–1.070631	–0.9	0.284336	No trend
POBE	–0.315282	–0.283333	0.752547	No trend
SAKETE	1.045433	1.198519	0.295823	No trend
SAVE	–3.44162	–4.317532	0.000578	Decreasing

3.2 *Analysis of MK test*

Table 2 presents the trend analysis across all stations with the Mann-Kendall test. The table contains the normalised Z statistic, the Sen's slope ss, the p-value, and the nature of the trend. The trend is significant when the p-value is less than 5%. Three of the 11 stations (Bembereke, Natitingou and Savè) got a downward trend at the 5% level. The Sen's slope is −4.317 at Savè, −3.450 Bembereke and lower at Natitingou (−1.8). Ahokpossi (2018) with 1940–2015 data gets a trend only on the station of Natitingou, a trend of course downward, with the same original Mann-Kendall test at the threshold of 5%. These results displayed by Mann-Kendall do not confirm those of Gnanglè et al. (2011) nor Obada et al. (2018).

3.3 Analysis of ITA test

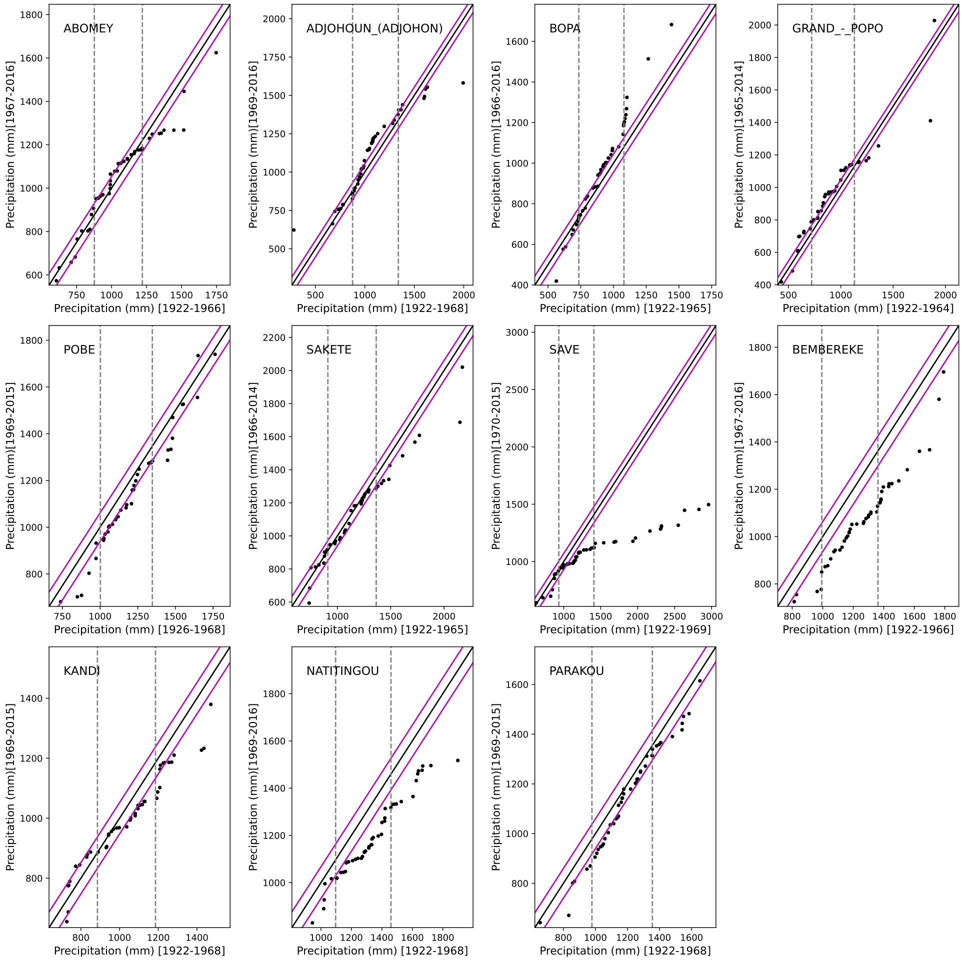
Table 3 shows trends according to the ITA method. The values in the table are the slope, the confidence interval at the proposed 5% threshold based on the method, and then the D magnitude of Wu and Qian (2017) and the nature of the trend. All the trends obtained are significant except Abomey where no trend appears. Rainfall is increasing in Adjouhoun, Bopa and Grand-Popo and the Şen's slopes are 0.79, 1.18 and 0.73 respectively. The trend on the rest of the stations is downward, the slope of Şen varies between −0.91 by Kandi and −7.59 in Savè. It is important to note that all stations in the north show a downward trend, while in the south, the south and south-west show an upward trend and in the southeast a downward trend. This disparity noted in the south can be explained by the fact that precipitation in the region is convective and generated by the eastern front. Column D of Table 3 shows the results of the trend index proposed by Wu and Qian (2017). The indices indicate the trends observed by calculation with the Şen's slope (Şen, 2014). These values vary between 0.166 and 0.283 for upward trends and between 0.199 and 1.195 for downward trends. Savè has the lowest index, so the highest is obtained in Bopa. The difficulty with the index method is that it does not allow the significance of the result to be assessed.

Table 3 ITA test

Stations	*Slope*	*CL*	*D*	*Trend*
ABOMEY	–0.255859	0.262535	–0.052872	No trend
ADJOHOUN	0.791884	0.423423	0.166219	Increasing
BEMBEREKE	–4.225758	0.214646	–0.732994	Decreasing
BOPA	1.181078	0.111322	0.282673	Increasing
GRAND-POPO	0.734275	0.424231	0.16604	Increasing
KANDI	–0.914847	0.171735	–0.199083	Decreasing
NATITINGOU	–3.122572	0.171173	–0.536239	Decreasing
PARAKOU	–1.249399	0.14147	–0.237549	Decreasing
POBE	–1.590033	0.200675	–0.269986	Decreasing
SAKETE	–1.155973	0.309955	–0.203398	Decreasing
SAVE	–7.585314	0.768296	–1.19497	Decreasing

As for the graphic analysis, the downward trends are very clear on the stations of Bembéréké, Natitingou and more or less on Savè. Indeed, on these three stations, the points are well outside the defined interval. At the rest of the resorts, the trend is sometimes upward or downward depending on the rain classes. On the majority of stations, the trends in the high cumulus class are well distinguished and are declining in Abomey, Adjohoun, Grand-Popo, Sakété, Bembéréké, Kandi and Natitingou. They are up only on the Bopa station. This shows that surplus years are decreasing except in Bopa. In the middle class of annual cumulus, the trends are significantly higher in Adjohoun, Bopa and Grand-popo and then lower in Bembéréké, Natitingou. In the class of low cumuls, the trends are significantly down in Pobè and then in Bembéréké.

Figure 4 ITA for annual rainfall at the 11 stations in Benin (see online version for colours)



4 Conclusions

This study assessed the precipitation trend at long-range stations in the Republic of Benin. The selected stations are those that have operated for at least 80 years with less than ten percent of missing data. The standard Mann-Kendall method and the innovative Şen method of analysis were applied to the aggregations of 11 selected stations. Mann-Kendall detects the trend on three stations, which is downward, while the innovative method finds the trend on ten out of 11 stations, three of which are upward.

High accumulation classes show a remarkable trend, which can be useful in decision making.

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