Differences and similarities between precipitation patterns of different climates

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Received: 25 May 2021 / Accepted: 16 August 2021 / Published online: 5 September 2021
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Abstract

In recent years water-related issues are increasing globally, some researchers even argue that the global hydrological cycle is accelerating, while the number of meteorological extremities is growing. With the help of large number of available measured data, these changes can be examined with advanced mathematical methods. In the outlined research we were able to collect long precipitation datasets from two different climatical regions, one sample area being Ecuador, the other one being Kenya. Using the methodology of spectral analysis based on the discrete Fourier-transformation, several deterministic components were calculated locally in the otherwise stochastic time series, while by the comparison of the results, also with previous calculations from Hungary, several global precipitation cycles were defined in the time interval between 1980 and 2019. The results of these calculations, the described local, regional, and global precipitation cycles can be a helpful tool for groundwater management, as precipitation is the major resource of groundwater recharge, as well as with the help of these deterministic cycles, precipitation forecasts can be delivered for the areas.

Keywords Precipitation · Climate · Spectral analysis · Groundwater · Kenya · Ecuador

1 Introduction

In recent years the impact of the ever-changing climate across the globe has caused several water-related problems (Szűcs and Ilyés 2019), more researchers argue that the hydrological cycle is in some way accelerated (Szöllősi-Nagy 2018), causing the growing number of meteorological extremes. This means that finding deterministic patterns getting more

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important. Since then, several researchers are trying to define the nature of these changes in the hydrogeological cycle (Miklós et al. 2020; Palcsu et al. 2017; Madarász et al. 2015; Kovács et al. 2015).

Using the available climatologic data, the changes in the hydrological cycle can be examined on several different locations over the world, such as in Eastern Africa and South America. With the help of spectral analysis, it is possible to define local, regional, and even global precipitation cycles in rainfall datasets to better understand the nature of the global climate.

Defining periodic components into precipitation datasets is important because with the help of these cycles and the use of advanced mathematical methods forecasts can be calculated for a given area for different time intervals, and different scales (Ilyés et al. 2019).

Different methods based on the discrete Fourier-transformation were previously used to define the regularities and patterns in hydrological datasets. The two main advanced methods are: (1) the Lomb-Scargle periodogram (Kovács et al. 2010) and (2) the Wavelet time series analysis (Nason and von Sachs 1999). These methods have been previously used to study the precipitation in California (Sangdan 2004), at Sanjiang Plane (Liu et al. 2009) and in Gannan County, China (Zheng et al. 2014), and Central-America (Hastenrath 1967), as well as for uneven records from multiple sites (Matyasovszky 2015). These methods have also been used in Hungary for several hydrometeorological and climate driven datasets (Kovács et al. 2010; Garamhegyi et al. 2018; Kovács and Turai 2014).

These DFT based methods have also been applied to long-term precipitation datasets, which cover the Carpathian-Basin, to examine the behavior of the precipitation and shallow groundwater levels in Central Europe (Ilyés et al. 2017, 2018). With the use of spectral analysis methods, the study was able to define deterministic cycles in precipitation datasets, which are useful tools for forecasting future precipitation totals. In that research, several annual and monthly datasets from the Hungarian precipitation datasets over the Carpathian-basin were investigated, and several regional and local periodic components were calculated using the spectral analysis method based on the discrete Fourier-transformation. The examined dataset clusters a group of annual datasets of 110 years.

Based on the obtained results, it was possible to understand more of the patterns and causes of these hydrometeorological data. There were 7 cycles defined from the annual precipitation data and 13 cycles from the monthly precipitation data as well as several local periodic components discovered from the available data.

Define these patterns in precipitation occurrence is an important decision-making tool for better groundwater management, as precipitation is the most important recharge source to the shallow and deep groundwater, so changes in the behavior of the precipitation events will eventually lead to changes in hydrodynamic behavior of aquifer layers.

In order to better understand the patterns defined locally in Hungary, collected datasets from different climatic areas on the Earth are also analyzed. It will help to define the precipitation cycles occurring globally and locally. With the expanded dataset, it aims to learn more about these processes on a global scale, and the forecasting method can be refined.

1.1 Climate characteristics of sample areas

1.1.1 Ecuador

The Ecuador location is between 75°11' and 81°01' west longitude, and 1°21' north latitude and 5° south latitude, on the west coast of South America, and the Intertropical

Zone. The global geological structures, known as (1) Ring of Fire, (2) Oceanic Dorsal, and (3) Transcontinental Structure perpendicular to the equatorial line (Paladines 2015), had an influence on the climate of the Ecuadorian continental territory due to the associated tectonic structures that produce a low temperature variability and a stationary precipitation pattern over the same location point.

As a result of the geological and tectonic facts, the continental territory of Ecuador is divided into three geographic strips:

1. The Littoral or Coast region is extended from Pacific Ocean to the eastern mountain flanks around 1000 m a.s.l. It is characterized by lowlands, sedimentary basins, foothill zone and a coastal strip with low elevation. With warm and dry weather in the south and tropical humid in the north, the warm current of El Niño, the cold current of Humboldt, and the close location to Andean Range affect the 2860 km² of the region (Barros and Troncoso 2010).

The climatic phenomena “El Niño” influence the precipitation rate over the land, but especially over the coastal region, and occurs with variable cyclicity every 2–7 years (Geovanny et al. 2015; Pan American Health Organization, 2000; Rossel 1997). The influence has been analyzed with stationary and monthly rainfall models, which conclude that the effects are evident with an increased number of intense precipitation days in March, April, May, and June over the influenced area of the phenomena. It has experienced a visible increase in intensity over the years (MAE, 2018).

2. The Mountainous or Highland region includes the occidental slope, the intermontane valleys, and oriental slope. With 800 km of longitude, it combines the Occidental Range, the Central Range, and the Oriental Range. These three ranks interlace themselves and form valleys and depressions with microclimates. In this zone emerges the recharge area of the major hydrographic systems of the country, which drain towards the Atlantic Ocean or the Pacific Ocean (Barros and Troncoso 2010).
3. The Oriental or Amazon Basin begins at 1000 m a.s.l., and extends from the oriental flank to the borders with Colombia and Perú. (Barros and Troncoso 2010). The region, dominated by warm, humid, and rainy weather, is divided on two areas: on the one hand, the High Amazon Region, composed of the lowlands of Napo, Galeras, Cutucú, and Córdor mountain ranges; on the other hand, the Amazon plain, with almost not altitude differences, and meander-anastomosed river systems.

At a distance of 972 km from the continent, a fourth natural region develops. It is known as the Galapagos Islands. There are 13 islands and 17 islets, with tropical weather during the first half of the year, and fresh weather during the second half when the Humboldt current arrives.

According to previous studies (Barros and Troncoso 2010; Moya 2006; Pourrut 1983; Winckell et al. 1997), 9 main weather classes occurs over the Ecuadorian territory. Each class combines three factors: (1) the annual precipitation regime, (2) the annual precipitation rate, and (3) the average annual temperature. The regimes can be equatorial, tropical, and uniform. Annual precipitation varies between 500 mm/year and 2000 mm/year, resulting in a climate between dry, semi-dry, and very humid. Meanwhile, the average annual temperature varies between 22 °C and 12 °C, and it is classified as Mega-thermic, Meso-thermic, or Cold.

1.1.2 Kenya

Kenya is located on the east coast of Africa, with the equator running almost straight through the middle of the country. Kenya borders with Somalia, Ethiopia and South Sudan in the north, Uganda in the west, Tanzania in the south and the Indian Ocean in the east. The territorial area is 582,646 km² and it is divided into water area of 11,230 km² and land area of 571,416 km².

Kenya's relief is characterized by a tremendous topographical diversity, ranging from glaciated mountains to a true desert landscape and stretches from sea level to about 5200 m a.s.l. at the peak of Mt. Kenya.

Its simplistic form is shown by the fact that the relief can easily be separated into lowlands and highlands, while diversity is exemplified by the presence of varied landform types, which according to be divided into smooth and irregular plains, escarpments, hills, and low and high mountains with breaks. The country generally experiences two seasonal rainfall peaks of long rains (March–May) and short rains (October–December) in most places. Mean annual rainfall over the country is 680 mm, which ranges from 250 to 2500 mm (WRI 2007; Businge 2011). It varies from about 200 mm in the arid and semi-arid zone to about 1,800 mm in the humid zone (GOK 2013; Paron et al. 2013). The distribution of rainfall in Kenya is irregular in time and space. The climate is characterized by alternating rainy and dry seasons. The average annual temperatures in Kenya range from < 10 to 30 °C (UNEP 2010).

The country can be divided into five major drainage basins (WRI 2007; Businge 2011), namely Lake Victoria, Rift Valley, Athi/Sabaki, Tana, and Ewaso Nyiro/North-Eastern Basin. Drainage is influenced by the country's topography and underlain geology (Paron et al. 2013).

To represent sample data for the whole country, the Athi River Basin was chosen because the acquisition of data will be readily available. The basin measures approximately 67000 km². The basin is located at the southern part of Kenya, east of the Rift Valley and drains the southern slopes of the Aberdares Range and the flanks of the Rift Valley, as well as the North Eastern slopes of Mount Kilimanjaro before draining into the Indian Ocean through the Athi River. The upper portion of the Athi river basin is a high potential agricultural and industrial area and covers major urban centers like Nairobi and Mombasa. The Athi River measures approximately 591 km, and has an average width of 44.76 m, average depth of 0.29 m and average flow rate of 6.76 m³/s (Businge 2011; GOK 2013).

2 Materials and methods

Several sample areas were defined for the calculations, all adequately representing the climatic conditions of the respective countries (Fig. 1).

Precipitation data from Ecuador were acquired from National Institute of Meteorology and Hydrogeology (INAMHI), with datasets covering the time interval between January 1990. and July 2019. The meteorological stations were strategically selected to be representative of the climate of the Coast, Highland and Amazon regions of the country.

The rainfall data from Kenya was obtained from the World Bank with the time interval covering the period from January 1980–December 2016 period (WB 2019).

Fig. 1 The location of the examined countries and measurement points

A self-developed Python software was used to perform the spectral analysis (GH 2020) required for the calculations.

Spectral analysis uses the tool of Fourier-Transformation, to convert the datasets from the time domain to the frequency domain, helping to find deterministic periodic components in otherwise stochastic time series data such as precipitation.

Harmonic functions were used to obtain the complex Fourier-spectrum, which is divided into an imaginary (Im) and a real (Re) part, and it is written as (Meskó 1984; Panther 1965):

$$\text{Re}[F(f)] = \int_{-\infty}^{+\infty} f(t) \cos(2\pi ft) dt \quad (1)$$

$$\text{Im}[F(f)] = - \int_{-\infty}^{+\infty} f(t) \sin(2\pi ft) dt \quad (2)$$

with the two parts calculated, the amplitude and the phase spectrum can be obtained:

$$A(f) = \sqrt{\text{Re}^2[F(f)] + \text{Im}^2[F(f)]} \quad (3)$$

$$\Phi(f) = \arctg \frac{\text{Im}[F(f)]}{\text{Re}[F(f)]} \quad (4)$$

The amplitude spectrum indicates the weight of the harmonic component at the origin of the signal falling into a frequency band unit around any frequency. The phase spectrum shows by what fraction of the period length the maximum of this harmonic component relative to the maximum of base function $\cos(2\pi ft)$. In spectral analysis, there are two different ways to

examine the time series. The first is the deterministic way; the other is the stochastic way, where we presume there are various random effects in the series (Candy 1985).

The relative amplitude spectrum is defined as the local maximum value of the amplitude compared to the absolute maximal amplitude found in the time series.

After defining the cyclic parameters, the amplitude, the phase angle and the frequency, the cycles with the relative amplitude spectrum over 50% were defined as major (dominant) cycles and cycles with relative amplitude spectrum between 20% (in some cases 10%) and 50% were defined as additional (minor) cycles.

For the Fourier transform of discrete data systems, DFT and FFT methods are most often used, which are based on the solution of a definite inhomogeneous system of linear equations. It is known that the noise present in the data system (measurement error) is then directly mapped to the frequency range, so the spectrum is also subjected to a noise load. It is known from the practice of geophysical inversion that setting and solving an overdetermined inverse problem offers an effective tool to reduce the effect of measurement errors. Fourier Transform as an inverse problem can be solved in the framework of row-expansion inversion (Dobróka et al. 2012).

In the case of the inversion Fourier transform, the continuous frequency spectrum is sequenced according to a suitably chosen $\Psi_n(\omega)$ frequency-dependent basis function system.

$$U(\omega) = \sum_{n=1}^M B_n \Psi_n(\omega) \quad (5)$$

where B_n denotes the complex row expansion coefficients and $\Psi_n(\omega)$ denotes the n th known basis function. In the case of the inversion structure of the Fourier transform, the method that solves the direct problem is the inverse Fourier transform, which in the case of the k th measurement sample is the

$$u^{(theor)}(t_k) = u_k^{(theor)} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} U(\omega) e^{j\omega t_k} d\omega. \quad (6)$$

can be defined in the form. Substituting Eq. (5), the calculated value can be given in Eq. (6)

$$u^{(theor)}(t_k) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \left(\sum_{n=1}^M B_n \Psi_n(\omega) \right) e^{j\omega t_k} d\omega = \sum_{n=1}^M B_n \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \Psi_n(\omega) e^{j\omega t_k} d\omega, \quad (7)$$

or introducing the Jacobi matrix:

$$G_{kn} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \Psi_n(\omega) e^{j\omega t_k} d\omega = F^{-1} \{ \Psi_n(\omega) \} \quad (8)$$

linear in the row expansion coefficients

$$u_k^{(theor)} = \sum_{n=1}^M B_n G_{kn} \quad (9)$$

we get to the equation. Expression (8) results in a matrix of size $N \times M$, where N denotes the number of measured data and M denotes the number of unknown members (row decomposition coefficients) considered in the row decomposition.

The model parameters included in Eq. (9) of the direct problem are the row expansion coefficients, the definition of which means the solution of the inverse problem. In the field of row-expansion geophysical inversion, it is expedient to use quadratic integrable, complete, orthogonal and normalized basis function systems to improve the numerical stability of the inversion problem (in order to eliminate the ambiguity problem). The correct choice of the basic functions is an important task, because if they are well chosen, a much smaller number of row coefficients than the number of data will approximate the frequency spectrum with sufficient accuracy, which is generally interpreted in the interval of real numbers $(-\infty, \infty)$. With this consideration, the choice of Hermite functions is expedient, since these are eigen functions of the Fourier Transform, so that the elements of the (8) Jacobi matrix can be computed without integration.

The algorithm of the inversion-based Fourier transform method can be defined in the usual framework by introducing the

$$e_k = u_k^{(meas)} - u_k^{(theor)} \quad (10)$$

deviation vector which L_2 norm minimized as

$$E_2 = \sum_{k=1}^N e_k^2 = \min. \quad (11)$$

we get the Gaussian least squares method, which has a normal equation

$$\underline{\underline{G}}^T \underline{\underline{G}} \vec{B} = \underline{\underline{G}}^T \vec{u}^{(meas)} \quad (12)$$

By solving the system of normal Eq. (9), the model parameter values (row expansion coefficients B_n) can be estimated

$$\vec{B} = (\underline{\underline{G}}^T \underline{\underline{G}})^{-1} \underline{\underline{G}}^T \vec{u}^{(meas)}, \quad (13)$$

knowing these, the frequency spectrum can be generated at any frequency

$$U^{estimated}(\omega) = \sum_{n=1}^M B_n^{estimated} H_n(\omega) \quad (14)$$

where $H_n(\omega)$ is the n th Hermite function. Robust inversion procedure while minimizing the weighted norm

$$E_w = \frac{1}{\sum_{s=1}^N w_s} \sum_{k=1}^N w_k e_k^2 = \min. \quad (15)$$

can be defined, where

$$w_k = \frac{\varepsilon^2}{\varepsilon^2 + e_k^2} \quad (16)$$

means Steiner weights (1988). The introduction of Steiner weights requires the application of the Iterative Re-Weighting Method (IRLS). In the procedure, we minimize the Eq. (10), which is not quadratic, because the weight matrix in the elements of the deviation vector

$$e_k = u_k^{(meas)} - u_k^{(theor)} = u_k^{(meas)} - \sum_{n=1}^M B_n G_{kn} \quad (17)$$

contains the unknown model parameters, the row decomposition coefficients B_n , so the inverse problem becomes nonlinear and can be solved by the IRLS method. With the inverse Fourier Transform method, the frequency spectrum and the characteristics derived from it can be determined with outstanding noise pressure.

3 Results

3.1 Ecuador

In Ecuador, the time interval used for the measurement was between Jan 1990 and July 2019, thus the length of the registration period, $T_{reg} = 355$ months, the sampling rate is 1 month, and the numbers of samples are 355 from each city. The Nyquist frequency is 2 months (Meskó 1984). The Nyquist-frequency shows the minimal length of time period that can be calculated correctly with the Fourier-transformation.

In the Coast region of the country, which is according to (Köppen 1884), arid desert and arid steppe, data from 3 monitoring stations were examined. The results show a significantly lower number of detected cycles over this area than the further ones.

In Bahía, 10 cycles were defined using the method (Fig. 2), with the 1 year length being the most dominant, all others being calculated as minor cycles. The cycles of 5.8 (~6), 7.93, 4.44 and 27.7 months length are the dominant ones.

At Pichilingue monitoring station, a small number of 9 cycles were also presented (Fig. 3), with the 1 year long as the most dominant. The second most dominant, and the leading of the minor cycles is the 6 month long period with 51% relative amplitude. All others are smaller periodic components, with 21-, 25.2- and 59-month lengths being dominant.

The same number of cycles was calculated in Olmendo, where the 1 year length has the highest relative amplitude (Fig. 4). In this case, all other periods were minor, with the 6 month length being the second with 37% relative amplitude. Other dominant minor cycles are the 44, 3 month-long cycles.

To conclude the coastal area, 10 periods were defined at the Bahía point, while 9 were defined at the Pichilingue and Olmendo stations. All monitoring points have cycles of 12, 6 and 3 months long, and several others were detected locally.

The Highland region, which is a tempered climate with no dry season (Köppen 1884), was represented also by 3 monitoring stations, namely Loja-La Argelia, Otavalo and Rumipamba-Salcedo.

At Loja-La Argelia monitoring point, 22 cycles were calculated using the method (Fig. 5). The most dominant is the cycle with a length of 1 year, and other important smaller cycles are the 36, 9, 3.1 and 4.1 months ones.

At Otavalo 32 cyclic components were defined (Fig. 6). Among them, the 12 month length has the highest amplitude, accompanied by a strong 6 month period in the data. The 2.44, 2.78, 3.1 and 4.78 months long periods were minor, but according to the relative amplitude, as the longer 45.7 and 80 months long.

In Rumipamba-Salcedo 23 cycles were calculated (Fig. 7), again the 1 year period is most dominant, but the 6 month cycle is also considered as major cycle. All other cycles

Fig. 2 Relative amplitude spectra of Bahía, according to monthly precipitation data

Fig. 3 Relative amplitude spectra of Pichilingue, according to monthly precipitation data

Fig. 4 Relative amplitude spectra of Olmendo, according to monthly precipitation data

Fig. 5 Relative amplitude spectra of Loja La Argelia, according to monthly precipitation data

Fig. 6 Relative amplitude spectra of Otavalo, according to monthly precipitation data

are minor, with the 3.11, 2.3, 3.7 and 34.8 month ones being also significant for rainfall patterns.

Looking at the area together, all the monitoring points had the 12, 6, 3, and the 2.3 month cycles in their data, as well as several others. The Otavalo station had the highest number of defined cycles, with 32, while Rumipamba had 23 and Loja-La Arge-lia had 23 cycles defined by the method, almost the same number of important periodic components.

The last examined area was the Amazon region, a tropical rainforest climate according to Köppen (1884), which is part of the Amazon river basin. From this part of the country 2 datasets were used for the examination.

At Nuevo Rocafuerte, 24 cycles were calculated (Fig. 8). The 1 year long cycle was calculated as the dominant one, and all other cycles were defined as minor. The 2.45, 4.3, 5.7–6.7 and 43 month cycles were important for high amplitude, with relative amplitude values between 40 and 20%.

A large number of cycles—30—were defined in Puyo (Fig. 9). The only two major cycle is the 1 year and 6 month long ones, with important minor cycles with 2.04, 2.3, 2.9–3.0, 3.7, 4.7 and 20.3 month long period of times and relative amplitude range between 40–25%.

At the monitoring points of the Amazon 24, and 30 cycles were detected. This number of cycles represents a more deterministic precipitation dataset, with a high number of local periods.

The most common cycles from the two datasets were the 12, 6, 4, 2.4 month long ones.

Fig. 7 Relative amplitude spectra of Rumipamba, according to monthly precipitation data

Fig. 8 Relative amplitude spectra of Nuevo Rocafuerte, according to monthly precipitation data

Fig. 9 Relative amplitude spectra of Puyo, according to monthly precipitation data

3.2 Kenya

In case of the calculations of the Kenyan data, the registration period is 1980–2016, thus the length of the registration period, $T_{\text{reg}} = 444$ months, the sampling rate is 1 month, and the numbers of samples are 444 from each city. The Nyquist frequency is 2 months.

From the country of Kenya 3 different climatic areas were covered by the 5 monitoring points which cover the southern-central part of the country, as no available measurements were taken in the northern arid part of the country.

First the coastal tropical savannah climatic area was examined (Köppen 1884). At Moi International monitoring point 18 cycles were detected (Fig. 10), with the 6 month long being the most powerful one, with the highest amplitude, and the 1 year long one, with almost half as much. The other cycles which were defined are minor cycles, with the amplitude range between 18 and 38%. The dominant minor cycles are the 3, 4, 29, and 2.4 month long ones.

At Mtwapa, 11 cycles were calculated (Fig. 11), also the most dominant was the half year long, with the 1 year long period with 83% relative amplitude. All of the other cycles were minor ones, with the 3, 4, and 7.6 month long ones being the dominant.

By examining the tropical coastal area's two stations together, At Moi International 18, while at Mtwapa 11 cycles were calculated. The most common were the 6, 12, 3, 4, 2.4, 2.85, and 29.6 month long cycles in both datasets.

From the central part of the country, which is arid, by the Köppen classification 2 stations were chosen (Köppen 1884).

Fig. 10 Relative amplitude spectra of Moi International, according to monthly precipitation data

Fig. 11 Relative amplitude spectra of Mtwapa, according to monthly precipitation data

At Dagoretti Corner 16 cycles were detected (Fig. 12), the half year long period with the highest amplitude, as seen in the other part of the country. The second major cycle is the 1 year long. All the other periodic components are belonging in the minor cycles group, with the 4, 7.4, and 3.55 month long ones appearing with relative amplitude above 20%.

At the Machakos monitoring point 18 cycles were calculated (Fig. 13). At this case, the two periods with the highest amplitude are the 6 and 12 month long ones with relative amplitude of 96 and 100% respectively. The only other major cycle is the 4 month long ones, the dominant minor cycles detected are the 2.4, 34.1 and the 4.11 month long one periods.

If the area is examined together, the 12, 6, 4, 29.6, 3.55, and 7.4 month long cycles were calculated from both datasets.

From the temperate western part of the country, only one dataset was available (Köppen 1884). From the station of Nyahurui 22 cycles were calculated with this method (Fig. 14).

From the dataset the 12, 4, 37, 7.79, 9.6, 14.3, and 2.51 month long precipitation cycles were defined. Interestingly the half year long cycle was not calculated from this data with the method.

4 Discussion

It is clearly seen from the results of the calculations, that there are several deterministic components present in all of the different datasets. To better understand the climatic patterns of these areas the comparison of the results is necessary.

Fig. 12 Relative amplitude spectra of Dagoretti Corner, according to monthly precipitation data

Fig. 13 Relative amplitude spectra of Machakos, according to monthly precipitation data

Fig. 14 Relative amplitude spectra of Nyahuruu, according to monthly precipitation data

The most predictable results were the strong presence of the 1 year long cycle in all of the datasets, with different amplitude. The reason behind this pattern is the 1 year long movement of the Earth itself. As for the detailed result, not in all cases was the 12 month long period the strongest, there were several monitoring points, where the half year long cycle was more dominant. The main reason behind it could be the difference in the seasons of these areas. Where there are only two major seasons, the half year long periodicity is stronger than in other areas., where 4 definite seasons can be found. It is also important to discuss that there were stations with no half year long cycle.

The other main cycles which were present in most of the monitoring stations are the 3, 2.5–2.8 month long ones, meaning there are global climatic, rather than local reasons behind it. The global reasons behind the interannual cycles are still mainly unresolved. Cyclic values lying between 2 and 2.9 years are probably associated with the Quasi-Biennial Oscillation (QBO), whilst those at 5–6 years may represent an harmonic of the ‘11–13 year’ solar cycle, or alternatively, may be related to El Niño Southern Oscillation (ENSO) which has recently been shown to influence both the North Atlantic Oscillation (O’Sullivan et al. 2002).

To better evaluate the results, we compared it to previous research, with a similar method from Hungary.

As known, the 1 and half year long cycle were also determined in Hungary (Ilyés et al. 2017), while from monthly data a strong 5 year long period were also calculated, which were not present in other regions. Because of the different time interval of the used data, the longer periods were not calculated from the precipitation datasets of Ecuador and Kenya, but the in the smallest cycles, there are some similarities.

In the case of Ecuador only local similarities can be found. Two measurement points had a 13–14 month long period defined (Rumipamba Salcedo and Olmendo), while 3 of them, Nuevo Rocafuerte, Otavalo and Olmendo, have a 42–43 month long one. The 4.8–5 month long one period was calculated from 5 different station such as Rumipamba-Salcedo, Nuevo Rocafuerte, Loja- La Argelia, Otavalo, Puyo and Bahía. The 28–29 month long period was calculated from Bahía and Otavalo.

In the case of Kenya broader similarities can be found. The 4.8–5 and the 28–29 month long one periods were calculated in all of the 5 monitoring stations as well as in Hungary, while there are 3 cycles which were present in 3 different locations, such as the 33–34 month long one in Dagoretti, the 13 month long one in Machakos, and the 14.5 month long one in Nyahuru. These can be caused by local effects.

The comparison shows that the 3, 4.8–5 month and the 28–29 month long periods can be caused by global climatic behavior, while the other similarities can be the effect of local weather phenomena.

5 Conclusions

The long-term precipitation data of two mainly different climatic regions were examined with the method of spectral analysis based on the discrete Fourier-transformation. The used method is capable of the definition of deterministic components in another way stochastic time series, such as precipitation.

With the help of the method, and comparing the results with previously calculated Hungarian data, the global behavior of the precipitation patterns was identified, with several cycles calculated from the used datasets. Most of the periods were local precipitation

cycles, while many of the calculated deterministic components showed similarities with cycles calculated from entirely different locations around the world. The reason behind the similar cyclic behavior is mostly unknown, for the future, finding these causes is important to better understand the global weather.

The results help understand the patterns in the rainfall events, with the defined cycles forecasts can be delivered for the future, and it can be an aid for future groundwater management practices, since precipitation is the main source of the natural groundwater recharge.

For the future, solving the problem with the inverse DFT method, with Steiner-weights can be helpful to reduce the noise in the dataset, thus giving more reliable result as well as improving the examination with statistical analysis.

Acknowledgements The research was carried out at the University of Miskolc both as part of the "More efficient exploitation and use of subsurface resources" project implemented in the framework of the Thematic Excellence Program funded by the Ministry of Innovation and Technology of Hungary (Grant Contract reg. nr.: NKFIH-846-8/2019) and the project titled as "Developments aimed at increasing social benefits deriving from more efficient exploitation and utilization of domestic subsurface natural resources" supported by the Ministry of Innovation and Technology of Hungary from the National Research, Development and Innovation Fund in line with the Grant Contract issued by the National Research, Development and Innovation Office (Grant Contract reg. nr.: TKP-17-1/PALY-2020).

Authors' contributions YF, VW Country profiles, and interpretation of results; CsI Methods, materials, results, and discussion. PSz Introduction, conclusions, discussion.

Funding Open access funding provided by University of Miskolc. The research was carried out at the University of Miskolc both as part of the "More efficient exploitation and use of subsurface resources" project implemented in the framework of the Thematic Excellence Program funded by the Ministry of Innovation and Technology of Hungary (Grant Contract reg. nr.: NKFIH-846-8/2019) and the project titled as "Developments aimed at increasing social benefits deriving from more efficient exploitation and utilization of domestic subsurface natural resources" supported by the Ministry of Innovation and Technology of Hungary from the National Research, Development and Innovation Fund in line with the Grant Contract issued by the National Research, Development and Innovation Office (Grant Contract reg. nr.: TKP-17-1/PALY-2020).

Availability of data and material All data available online at Worldbank (<https://climateknowledgeportal.worldbank.org/download-data>), National Institute of Meteorology and Hydrogeology (INAMHI).

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Code availability The self-developed software for implementing the calculations is available at: <https://github.com/europe-gis/met-analytics/tree/master/Fourier>

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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