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The Drought Indices Calculator (DrinC)

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Abstract: Drought is a natural hazard characterised mainly by three dimensions: severity, duration and areal extent. Although several simplifications were proposed for the analysis of droughts for assisting water managers and policy makers to address this complex phenomenon, drought severity remains the key factor for the characterisation of drought. Drought severity is conventionally assessed by drought indices, which are simple or composite indicators useful for identifying and monitoring drought events in a meaningful way. The paper reports on a specialised software package, named DrinC (Drought Indices Calculator), which was developed aiming at providing a simple interface for the calculation of drought indices, with emphasis on two recently developed indices, the Reconnaissance Drought Index (RDI) and the Streamflow Drought Index (SDI). The software can also be used for the calculation of the Standardised Precipitation Index (SPI) and the Rainfall Deciles. Additionally, DrinC includes a module for the estimation of potential evapotranspiration (PET) through temperature based methods (Hargreaves, Blaney-Criddle and Thornthwaite), that can be used for the calculation of RDI. Finally, the software package incorporates useful tools assisting in the customisation of drought scenarios for fulfilling the requirements of a wide range of decision making cases. In the paper, a brief description of the theoretical basis of the aforementioned drought indices is also presented, together with some practical applications.

Key words: Drought indices, Rainfall Deciles, Reconnaissance Drought Index (RDI), Streamflow Drought Index (SDI), Standardized Precipitation Index (SPI), software package.

1. INTRODUCTION

Drought is a natural hazard that may have significant effects on human activities and the environment. Therefore, it is important to be able to assess the magnitude of drought that will assist the evaluation of drought consequences and the process to mitigate the anticipated effects.

Drought indices are essential tools for the characterization and the monitoring of drought, since they simplify the complex climatic functions and can quantify climatic anomalies as for their severity, duration and frequency. They are also very useful as they can communicate to the wider audience easily comprehensible information regarding the severeness of drought episodes (Tsakiris et al., 2007a).

Therefore, drought indices can be used in the academic field (education, research, studies etc.), but also at strategic and operational levels (decision making, proactive management and drought mitigation etc.), having a wide range of potential users. The development of specialised software for the calculation of drought indices, that provides to the end-user a simple interface and produces clear and comparable outputs, may be very helpful for both academic and operational use. Further, the comparison of the results of several drought indices may lead to a comprehensive assessment of drought severity.

On this basis, DrinC software package was developed at the Centre for the Assessment of Natural Hazards and Proactive Planning and the Laboratory of Reclamation Works and Water Resources Management of the National Technical University of Athens. DrinC (Drought Indices Calculator) aims at providing a user-friendly tool for the calculation of several drought indices, with emphasis on two recently developed ones: the Reconnaissance Drought Index (RDI) and the Streamflow Drought Index (SDI). Also, the widely used Standardised Precipitation Index (SPI) and the Rainfall Deciles can be calculated through DrinC. The common characteristic of the selected indices is that they require relatively small number of data for their calculation and the results can be easily interpreted and used in strategic planning and operational applications.

The calculation process is performed through a windows-based interface and there are several options that can be used for the characterisation of drought for each case study. Further, DrinC includes some additional modules e.g. for the calculation of potential evapotranspiration (PET) through temperature-based methods.

2. DROUGHT INDICES

2.1 Rainfall Deciles

A simple meteorological drought index is the Rainfall Deciles, in which the precipitation totals for the preceding three months are ranked against climatologic records. If the sum falls within the lowest decile of the historical distribution of 3-month totals (Table 1), then the region is considered to be under drought conditions (Kininmonth et al., 2000). The drought ends when: (i) the precipitation measured during the past month already places the 3-month total in or above the fourth decile, or (ii) the precipitation total for the past three months is in or above the eighth decile.

The first decile is the precipitation amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. These deciles continue until the rainfall amount identified by the tenth decile is the largest precipitation amount within the long-term record. By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record. The deciles are grouped into five classifications. Table 1 presents the classification of drought conditions according to deciles.

Table 1. Classification of drought conditions according to deciles.

Decile Classifications	Description
deciles 1-2: lowest 20%	much below normal
deciles 3-4: next lowest 20%	below normal
deciles 5-6: middle 20%	near normal
deciles 7-8: next highest 20%	above normal
deciles 9-10: highest 20%	much above normal

The advantage of the decile approach is its computational ease, but its simplicity can lead to conceptual difficulties. For example, it is reasonable for a drought to terminate when observed rainfall is close to or above normal conditions. But minor amounts of precipitation during periods in which little or no precipitation usually falls, can activate the first stopping rule, even though the amount of precipitation is trivial and does not terminate the water deficit. A supplemental third rule, that considers the total precipitation since the beginning of drought, may be used (Keyantash and Dracup, 2002). According to this rule, if the total precipitation exceeds the first decile for all drought months, then the meteorological drought may be considered terminated.

2.2 Reconnaissance Drought Index (RDI)

Drought severity can be assessed through the computation of the Reconnaissance Drought Index (RDI) and more precisely through its standardised form (RDI_{st}). The RDI was developed to approach the water deficit in a more accurate way, as a sort of balance between input and output in a water system (Tsakiris and Vangelis, 2005; Tsakiris et al., 2007a). The RDI is based both on cumulative precipitation (P) and potential evapotranspiration (PET), which are one measured (P) and one calculated (PET) determinant. The calculation method of PET, however, does not seem to affect the results of RDI in any way (Vangelis et al., 2013). The initial value (α_k) of RDI is calculated for the i-th year in a time basis of k (months) as follows:

$$\alpha_k^{(i)} = \frac{\sum\limits_{j=1}^{k} P_{ij}}{\sum\limits_{j=1}^{k} PET_{ij}} \ , \ i = 1(1)N \ \text{ and } \ j = 1(1)k \tag{1}$$

in which P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the j-th month of the i-th year and N is the total number of years of the available data.

The values of α_k follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they were tested (Tigkas, 2008; Tsakiris et al., 2008). By assuming that the lognormal distribution is applied, the following equation can be used for the calculation of RDI$_{st}$:

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \overline{y}}{\hat{\sigma}_y} \tag{2}$$

in which y_i is the ln($a_k^{(i)}$), $\overline{y}$ is its arithmetic mean and $\hat{\sigma}_y$ is its standard deviation.

In case the gamma distribution is applied, the RDI$_{st}$ can be calculated by fitting the gamma probability density function (pdf) to the given frequency distribution of α_k (Tsakiris et al. 2008; Tigkas 2008). For short reference periods (e.g. monthly or 3-months) which may include zero values for the cumulative precipitation of the period, the RDI$_{st}$ can be calculated based on a composite cumulative distribution function including:
-   the probability of zero precipitation, and
-   the gamma cumulative probability.

Positive values of RDI$_{st}$ indicate wet periods, while negative values indicate dry periods compared with the normal conditions of the area. The severity of drought events increases when RDI$_{st}$ values are getting highly negative. Drought severity can be categorised in mild, moderate, severe and extreme classes, with corresponding boundary values of RDI$_{st}$ (-0.5 to -1.0), (-1.0 to -1.5), (-1.5 to -2.0) and (< -2.0), respectively. RDI is calculated for a hydrological year in 3, 6, 9 and 12 month reference periods. This implies the different nature of RDI in comparison to other drought indices, since RDI is calculated for predetermined reference periods and not as a "rolling" index of constant duration.

2.3 Streamflow Drought Index (SDI)

According to Nalbantis (2008), if a time series of monthly streamflow volumes $Q_{i,j}$ is available, in which i denotes the hydrological year and j the month within that hydrological year ($j = 1$ for October and $j = 12$ for September), $V_{i,k}$ can be obtained based on the equation:

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \ \ i = 1, 2, \ldots \ \ \ j = 1, 2, \ldots, 12 \ \ \ k = 1, 2, 3, 4 \tag{3}$$

in which $V_{i,k}$ is the cumulative streamflow volume for the i-th hydrological year and the k-th reference period, $k = 1$ for October-December, $k = 2$ for October-March, $k = 3$ for October-June, and $k = 4$ for October-September.

Based on the cumulative streamflow volumes $V_{i,k}$, the Streamflow Drought Index (SDI) is defined for each reference period k of the i-th hydrological year as follows:

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V}_k}{s_k} \ \ i = 1, 2, \ldots, \ \ \ k = 1, 2, 3, 4 \tag{4}$$

in which $\overline{V}_k$ and s_k are respectively the mean and the standard deviation of cumulative streamflow volumes of the reference period k as these are estimated over a long period of time. In this definition the truncation level is set to $\overline{V}_k$ although other values based on rational criteria could be also used.

Generally, for small basins, streamflow may follow a skewed probability distribution which can well be approximated by the family of the gamma distribution functions. The distribution is then transformed into normal. Using the two-parameter log-normal distribution (for which the normalisation is simply reclaiming the natural logarithms of streamflow), the SDI index is defined as:

$$\text{SDI}_{i,k} = \frac{y_{i,k} - \overline{y}_k}{s_{y,k}} \quad i = 1, 2, \ldots, \quad k = 1, 2, 3, 4 \tag{5}$$

in which

$$y_{i,k} = \ln(V_{i,k}), \, i = 1, 2, \ldots, \quad k = 1, 2, 3, 4 \tag{6}$$

are the natural logarithms of cumulative streamflow with mean $\overline{y}_k$ and standard deviation $s_{y,k}$ as these statistics are estimated over a long period of time.

According to Nalbantis and Tsakiris (2009) states (classes) of hydrological drought are defined for SDI in an identical way to those used in the meteorological drought indices SPI and RDI. Five states are considered which are denoted by an integer number ranging from 0 (non-drought) to 4 (extreme drought) and are defined through the criteria of Table 2.

Table 2. Definition of states of hydrological drought with the aid of SDI.

State	Description	Criterion
0	Non-drought	$\text{SDI} \geq 0.0$
1	Mild drought	$-1.0 \leq \text{SDI} < 0.0$
2	Moderate drought	$-1.5 \leq \text{SDI} < -1.0$
3	Severe drought	$-2.0 \leq \text{SDI} < -1.5$
4	Extreme drought	$\text{SDI} < -2.0$

2.4 Standardized Precipitation Index (SPI)

The Standardised Precipitation Index (SPI) was developed by McKee et al. (1993) to serve as a "versatile tool in drought monitoring and analysis". The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Since SPI is normalized, wetter and drier climates can be represented in the same way. Although SPI can monitor wet periods, it is typically used to assess the length and magnitude of drought events.

Thom (1958) found the gamma distribution to fit well to the climatological precipitation time series. The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^a \Gamma(a)} x^{a-1} e^{-x/\beta}, \quad \text{for } x > 0 \tag{7}$$

in which a and β are the shape and scale parameters respectively, x is the precipitation amount and $\Gamma(a)$ is the gamma function. Parameters a and β of the gamma pdf are estimated for each station and

for each time scale of interest (1, 3, 6, 9, 12 months, etc.). Maximum likelihood estimations of a and β are:

$$a = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right), \ \beta = \frac{\bar{x}}{a}, \quad \text{where} \quad A = ln(\bar{x}) - \frac{\sum ln(x)}{n} \tag{8}$$

and n is the number of observations.

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the location in question. Since the gamma function is undefined for $x = 0$ and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q)G(x) \tag{9}$$

in which q is the probability of zero precipitation and $G(x)$ is the cumulative probability of the incomplete gamma function. If m is the number of zeros in a precipitation time series, then q can be estimated by m/n. The cumulative probability $H(x)$, is then transformed to the standard normal random variable z with mean zero and variance of one (Abramowitz and Stegun, 1965), which is the value of the SPI.

According to the SPI, a drought event occurs when the index continuously reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. Drought magnitude is the positive sum of the SPI for each month during the drought event (Hayes et al., 2007).

The SPI can track drought on multiple time-scales. It is usually computed with five running time intervals, i.e. 1-, 3-, 6-, 9-, and 12-months, but the index is flexible with respect to the period chosen, which depends on the amount of information needed by the researcher. Moreover, being a standardized index, the SPI is particularly suited to compare drought conditions among different time periods and regions with different climatic conditions.

Generally, monthly precipitation is not normally distributed so a transformation is performed such that the derived SPI values follow a normal distribution. The SPI is the number of standard deviations that the observed value would deviate from the long-term mean, for a normally distributed random variable. One interpretation of the resultant values is presented in Table 3 (Tsakiris and Vangelis, 2004).

Table 3. Classification of drought conditions according to the SPI.

SPI values	Classification
2.0+	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-.99 to .99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 and less	Extremely Dry

3. SOFTWARE OVERVIEW

3.1 Software interface

DrinC has full graphical user interface functionality (GUI) and runs on MS Windows operating systems (Figure 1). During the development of the software package has been given emphasis on

maintaining a simple, comprehensive and user-friendly structure. All the main functions can be accessed through the main menu of the software, and in each window there are several additional options for each operation.
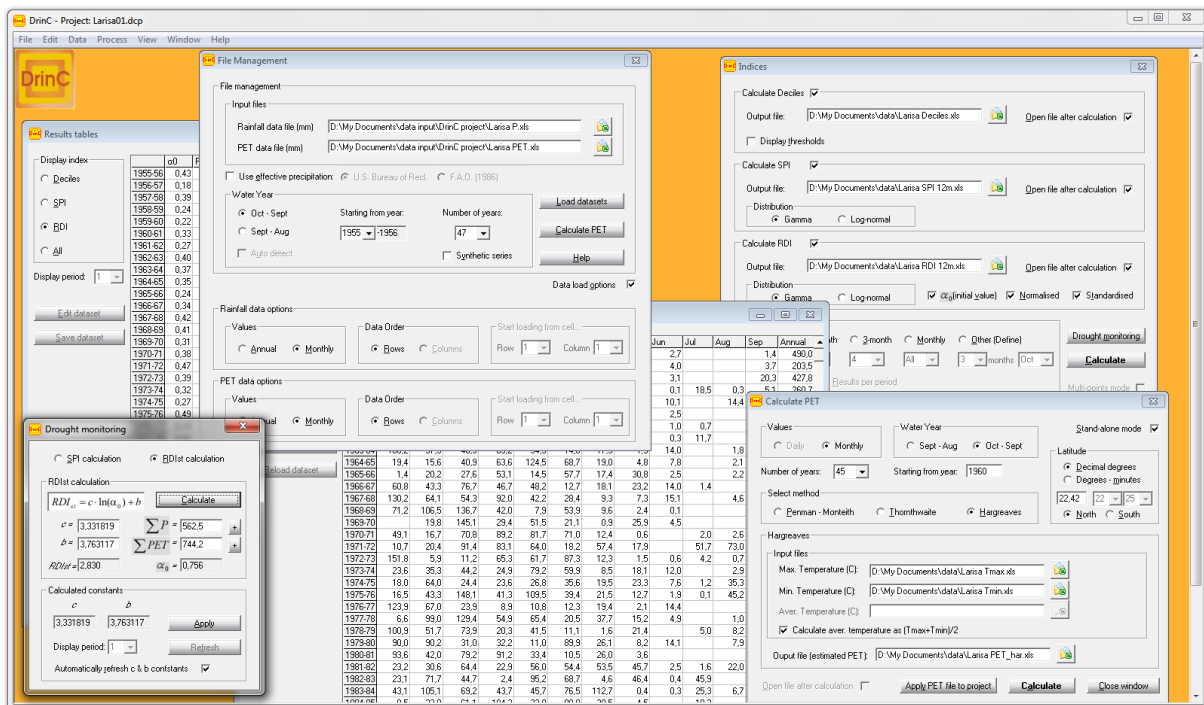

Figure 1. The graphical user interface (GUI) of DrinC.

3.2 Data management

The calculation of each index requires different input data, as can be seen in Table 4. Data can be imported directly from MS Excel files, manually or automatically. Data can be either monthly or annual and there is an option to use real (up to 150 years) or synthetic (up to 1500 years) data series. There is also the option to transform rainfall data into effective rainfall data.

Table 4. Required input data for each index.

Index	Required input data
Rainfall Deciles	Precipitation
RDI	Precipitation, PET (or temperature)
SPI	Precipitation
SDI	Streamflow

Imported data are loaded in a management window (Figure 2) where they can be reviewed and edited.

Figure 2. Management window of imported data.

3.3 PET calculation

DrinC provides a module (Figure 3) for the calculation of potential evapotranspiration (PET) with the following temperature based methods:
- Hargreaves and Samani (1982, 1985),
- Thorthwaite (1948) and
- Blaney – Criddle (Doorenbos & Pruitt 1977)

The first requires minimum and maximum temperature data, whereas the other two require only mean temperature data.

Figure 3. PET calculation module of DrinC.

3.4 Drought indices calculation

The drought indices can be calculated through an adaptable procedure, giving the user the ability to formulate the parameters that suit better to the needs or the purpose of each study. For example, the initial theoretical concepts of SPI and RDI are different, since SPI is calculated in a monthly sequential order (McKee, 1993), while RDI is calculated for discrete periods on water year basis

(Tsakiris et al., 2007a). In DrinC there is the option to use both approaches for each index, which also allows the comparison of the results between RDI and SPI. Further, the use of gamma or log-normal distributions may be selected.

The primary reference base in DrinC is the hydrological year (October – September), therefore the default calculation period starts from October and the main time steps are monthly, 3-months, 6-months and annual. However, it is possible to define other time steps (e.g. 4-months) or starting months (e.g. January). This flexibility may be useful for several real world applications. For instance, the study of drought effects on specific crops should coincide to the crop growth period. Also there is the option to calculate the drought indices sequentially for each month and the output may be presented per month or per period in order to have a direct comparison of drought severity of specific periods for each year.

The results can be saved in MS Excel files (Figure 4) and the user may select the output format and other options (e.g. automatically drawn graphs).
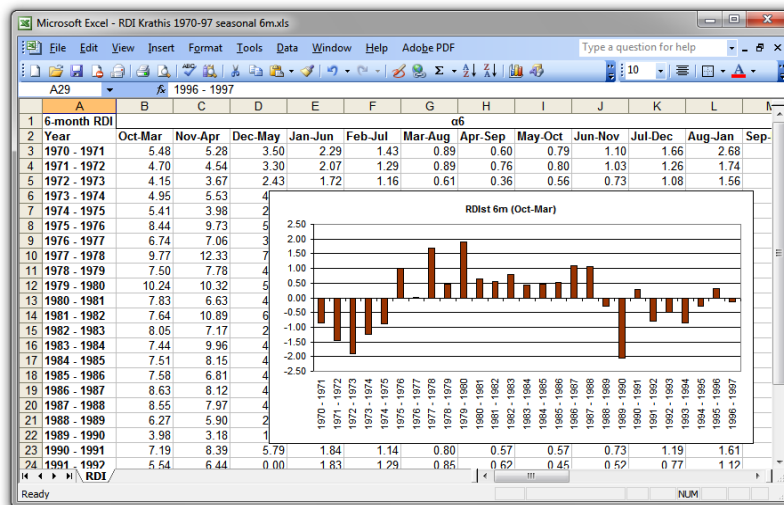

Figure 4. Example of an output file of DrinC.

Another useful feature of the package is the 'multi-points mode' function, with which a set of input data for several spatial points can be loaded and each drought index can be calculated for each point through an iterative routine. This automated procedure for the assessment of spatial distribution of drought indices may be used for the production of drought maps.

3.5 Drought monitoring

Drought monitoring is a key operational tool for the early warning for drought events and for the better management of the anticipated drought consequences (Wilhite et al. 2005, Bordi & Sutera 2007). Drought monitoring systems are operating in several countries and wider areas including neighbouring countries (WMO, 2006).

With the drought monitoring module of DrinC, drought indices can be directly estimated using real-time data, if there are sufficient available data for a reference period in order to depict the climatic behaviour for the area of study. It is assumed that the climatic characteristics of the study area remain the same for both the monitoring and the reference periods.

The procedure is based on the linear function, which in case of RDI is:

$$RDI_{st} = c \cdot \ln(\alpha_n) + b \tag{10}$$

in which α_n is the initial value of RDI for *n*-months period, *c* and *b* are constants calculated from the reference period data for the *n*-months period.

4. APPLICATIONS

DrinC has been used in several applications and studies for drought assessment and monitoring, mainly in arid and semi-arid areas. Some application examples of DrinC in European and Asian countries are presented below:

- Malta: The Water Directorate of the Malta Resources Authority used DrinC to analyse drought events in the country through RDI and SPI. Also, there was an attempt to assess the problems that could be caused by water shortage due to severe drought events (Borg, 2009).
- Iran: The University of Isfahan and the Meteorological Organisation of Iran used DrinC in a study for the operational drought monitoring in the region of Isfahan. Meteorological data from 10 stations were used for the calculation of RDI and SPI (Mostafavi Darani et al., 2011).
- Greece – Crete: The Centre for the Assessment of Natural Hazards and Proactive Planning of the National Technical University of Athens (NTUA) studied drought episodes on a regional level at the island of Crete. A series of annual drought maps were produced with the use of DrinC along with a spatial distribution model (Tsakiris et al., 2007b).
- Greece – Thessaly: The University of Thessaly used DrinC to assess meteorological drought for a period of 45 years, using three drought indices (Deciles, Palmer Z and RDI) (Kanellou et al, 2008).
- Greece – Peloponnese: The Lab. of Reclamation Works and Water Resources Management of the NTUA used DrinC along with Medbasin rainfall-runoff model in order to assess the drought and climatic change impact on streamflow in small watersheds. The case study was performed in 6 small watersheds in N. Peloponnese. RDI was calculated for several reference periods (3, 6, 9 and 12 months) and SDI was used to represent hydrological drought. Regression equations were derived between RDI and SDI, forecasting the level of hydrological drought for the entire year. Further, DrinC was used for the formulation of a wide range of scenarios representing possible climatic changes and drought events of varying severity in the area of N. Peloponnese. Nomograms were devised for estimating the annual streamflow change caused by each climate change scenario (Tigkas et al., 2012).
- Italy: The Water Observatory of the Region of Sicily and the University of Palermo analysed time series of climatic data (rainfall, temperature) using drought indices (SPI, RDI, NDVI) and vegetation data at the Oreto watershed in Sicily. Both satellite and conventional measurements were used in order to assess climatic effects on vegetation at the study area (Capodici et al., 2008).
- Cyprus: The Meteorological Service of Cyprus has used DrinC in two studies for the assessment and the monitoring of drought in Cyprus, using an extensive network of meteorological stations and GIS techniques (Pashiardis and Michaelides, 2008; Michaelides and Pashiardis, 2008).

5. CONCLUDING REMARKS

In this paper the Drought Indices Calculator (DrinC) software package was presented. The software package facilitates the calculation of drought indices and assists institutions and stakeholders to share reliable estimation of the severity of each drought episode.

DrinC can also facilitate the quick evaluation of the drought severity for a number of possible future climatic scenarios.

It goes without saying that, since more than one drought indices can be easily calculated using DrinC, a quite comprehensive picture of drought severity can be obtained.

Finally, from the extensive applications of DrinC in various countries, it seems that it gradually gains ground for becoming a widely used software package for the drought severity assessment through the calculation of several drought indices.

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