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Remote Sensing Indexes Assessment for Drought Monitoring Using Sentinel Satellite Imagery: A Case Study from Natanz County, Iran

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In recent years, the problem of climate change and decrease in rainfall has become a big challenge in Iran, so it's monitoring and control is very vital and necessary. In addition to the classical methods, nowadays with the progress of the space industry in the world, the use of remote sensing techniques has greatly helped to detect and monitor drought. The science of remote sensing and the use of satellite images is considered a useful and optimal tool for drought monitoring. In this project, we investigated the occurrence of drought using satellite images and remote sensing techniques. In this way, we have calculated the drought-related remote sensing indicators, including NDVI, VCI, TCI, and VHI, in the six-year period between 2015 and 2021 for Natanz county located in Isfahan province. In order to calculate the indicators, Sentinel satellite data was

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used, and to calculate the Standard Rainfall Index (SPI), data from the synoptic station of Natanz county was used. According to the general results obtained from the indicators, currently the drought situation in the southwestern region of this area has been increasing compared to the last five years, and in other regions we are witnessing the growth and occurrence of drought sporadically. The results of this research show that the best index for calculating and monitoring drought is the VCI index because it has a higher correlation with meteorological data and the SPI index.

Keywords: Drought index; satellite imagery; remote sensing; sentinel satellite; sentinel; Natanz County.

1. INTRODUCTION

Drought is a complex, globally occurring phenomenon that affects humans and nature alike [1], because of excessive population growth and the increasing need for water [2], accompanied by rapid industrialization and urbanization [3]. Dou climate change and decrease precipitation trend drought is converted to the big challenge in the world specially dry and semi dry areas like Iran; Thus monitoring and management of this is an important issue.in front of traditional methods that depend on meteorological station observations and focused on more investigate to the meteorological drought, by using remote sensing technique and satellite imagery as a useful method for temporal and spatial agricultural monitoring are interested for researchers. Subsurface water storage situation in Iran is not affirmative. In recent decades value of subsurface water storage in Iran equal to 131 billion m^3 according to statistical tests reports, but in recent years it decrease to 111 billion m^3, also global warming and defect of precipitation caused this disaster. According to some researches average of precipitation was 275 mm have mentioned that represent the most part of Iran is dry and semi dry region [2]. So because of these problems and climate change of Iran, drought is an inevitable issue in this country therefore monitoring and investigation of this phenomenon is necessary.in this paper drought indicates have been evaluated by using satellite imagery and using remote sensing technique. Several studies had done in this field; Sepulcre - Canto et al [3], applied a combination of SPI, soil moisture anomaly, and the fraction absorbed photo synthetically to active Radiation, While Trnka et, al [4] used a combination of soil moisture data and EVI in the Czech republic and Slovakia. Both approaches were shown to be promising. Finally approaches also exist within this topic to determine areas and time periods were water is the primary limiting factor for plant growth.in Europe, a correlation analysis between LST and NDVI has revealed that energy was a limiting factor mainly in northern Europe at high altitude, and in spring while water limited plant growth mainly southern Europe in summer. Despite the large numbers of existing studies on agricultural and vegetation-based drought in central Europe using remote sensing uncertainties and larger knowledge gaps still exist [5]. Rezaei et al evaluated performance of temperature conditional index (TCI) and vegetation conditional index (VCI) using MODIS satellite images for estimating drought in Urmia lake; they concluded that MODIS satellite images have fine accuracy for estimating drought .they recommended remote sensing techniques except of meteorological methods due to better temporal resolution, less expenditure, more surface coverage and more resampling points [6]. Rezaei Banafshe et al for drought analysis at east Azarbayjan province by using MODIS satellite images from 2011 to 2017 computed the VCI (vegetation conditional index) they understood maximum drought depended on 2011, 2012 consequently, And minimum values depend on 2013 .for validation VCI results in 2 synoptic station data used and compare with SPI values for three months in 2011, 2012, 2013. This results represented according to SPI values confirm VCI values [7] .in 2006 Kogan et al evaluated Mongolia's drought by using AVHRR-NOAA satellite data; They found out that VHI had the best results on the other hand in Afghanistan, Pakistan and two country in west side of India Then kabaiand his coworkers estimated VHI, VCI, TCI and NDVI for drought monitoring. Their results represented that due to lack of ground observations, remote sensing have a very important role ,also they recommended merging AVHRR, MODIS daily data method in 2006 [8]. Dilayda Soylu Pekpostalci et, al demonstrated in their research that the emerging RS technology and satellite-driven indicators were rarely used in the country. The review showed that there is room for more research on agricultural and hydrological drought monitoring, forecasting, and pattern detection in Turkey [9]. Ziyu Wang et,al. used soil moisture was added to calculate a new drought index based on TVPDI in southeastern Tibet, named the Temperature–Vegetation–Soil-Moisture–Precipitation–Drought Index (TVMPDI). Then, the TVMPDI was validated by using the Standardized Precipitation Evapotranspiration Index (SPEI) and other remote sensing drought in-dices, including the Vegetation Health Index (VHI) and Scale Drought Conditions Index (SDCI), during the growing seasons of 2003–2018. [10] despite of the important role of Natanz county there isn't any new study about drought monitoring by using remote sensing technique ,in this study investigation of drought monitoring have been done by using several indexes to choose the best one for future studies by considering meteorological data of case study.

2. MATERIALS AND METHODS

In order to achieve the best accuracy and resolution, Sentinel 2 satellite images were used in this study, then, the images without extraneous noise were extracted from them and the data were subjected to atmospheric and radiometric correction. The data related to the precipitation of the target area was taken from the meteorological website of Iran, and based on this data, the SPI index was calculated with the resulting formula that will be stated in the following, and the other data related to temperature was also received from the same website and the calculation was done. In accordance with the necessity of calculating the NDVI index, the closest indices to temperature and NDVI were selected and obtained in the ENVI 5.6 software by using supervised method of classification Maximum likelihood method. The steps of the research are shown in the flowchart of Fig. 1**.**

2.1 Implementation of Classification Methods

Image classification methods are divided into 3 groups: supervised classification methods, unsupervised classification methods, and object-oriented classification methods [11].

2.1.1 Supervised classification methods

One of the most accurate and widely used methods among the various supervised classification methods is the maximum likelihood method [12]. This method evaluates the variance and covariance of different classes. It is assumed that all educational regions have a normal distribution function. After evaluating the probabilities in each class, the pixels are assigned to the classes that have the most similarity, and if the probability values are lower than the threshold, they introduce as unclassified pixel [13].

In this method of classification, there is a need for previous information and knowledge of the phenomena related to the data, and a number of pixels are introduced to the software as identifiers (training examples), then the software classifies the rest of the pixels according to specific instructions. In the following, some supervised classification methods are introduced.

2.2 Study Area

The case-study of this research is central part of Natanz county between 33˚ 25' and 33˚ 40' N and 51˚ 25' and 52˚ E. This region have mountains and deserts that a mountainous area with a maximum height of 2242 meters above sea level and a desert area with a height of 272 meters above sea level, it has 2 types of climate: cold, desert and temperate. From the north to Aran and Bidgol deserts, from the south to Mimeh is limited to Ardestan from the east and Kashan from the west. This county is located 752 km north of Isfahan, 72 km southeast of Kashan and 254 km from Tehran. Water of this area is provided from seasonal rivers and mostly from springs and aqueducts .average rainfall is 772 mm annually and there is no rainfall in the months of July, August and September. This issue indicates that the growing season of the plant without rain and the water from the winter rain is waste water, unavailable and unusable. Maximum degree of the absolute temperature is 4.22 degrees Celsius and the minimum absolute temperature is -4.72. Maximum humidity is 60% and minimum Average humidity is 34%. The dry season in this region is relatively long and starts from May to the end of October. February is the coldest month and the driest month July is the hottest month of the year. The rainiest month of the year is March, which is also the wettest month of the year [9] The data related to the precipitation of the region are shown in Fig. 3 and the SPI index.

2.3 Data

Sentinel data used for this research and compute NDVI and LST raster data then calculate drought indicates. These data was downloaded from USGS data center. Chosen period for all sentinel satellite product was from 2015 to 2021.The spatial resolution of sentinel 3 satellite images is 300 m and temporal resolution is 10 days [10]. On the other hand collecting meteorological data from ground synoptic station including pressure, temperature, humidity and rainfall that archived to the governmental organization which provided valid statistical parameters using high precision instruments [14] .by using previous parameters, Standard Precipitation Index (SPI) was calculated into monthly average. All of data in this research processed by ENVI 5.6 (The Environment for Visualizing Images) for computing VCI, TCI and VHI Indexes .In this research classification upon to maximum likelihood algorithm is used.

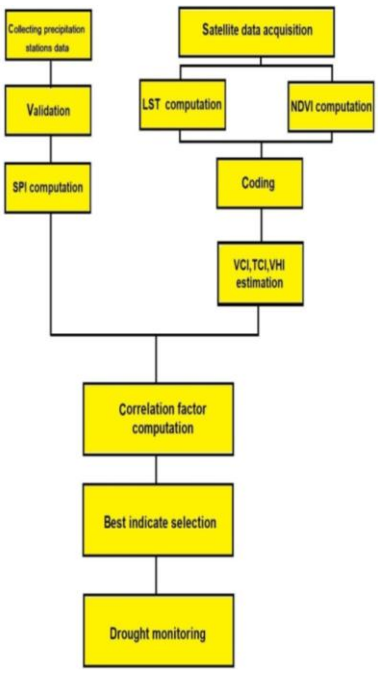

Fig. 1. Flew chart of method s sequence

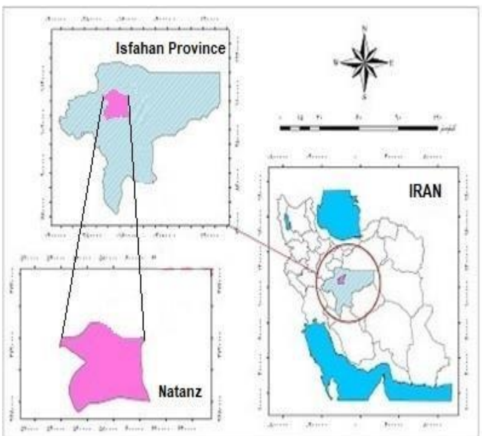

Fig. 2. Study area [9]

2.4 Calculation and Assessment of Drought Indices

VCI, TCI and VHI the SPI is the geo-referenced indicate which is computed upon from ground station data.

SPI is one of the basic indices, for its calculation, it is necessary to have the long-term average and standard deviation of rainfall values for the studied periods. Lack of precipitation in short-term time scales mainly affects soil moisture and long-term often affects underground water, river flow and water resource reserves [15]. This index can be calculated through equation 1:

$$\mathrm{SPI} = \frac{\mathrm{P_i} - \bar{\mathrm{P}}}{\mathrm{SD}} \qquad (1)$$

In this regard; SPI is the standard index of precipitation, P_i is the precipitation of the desired year in millimeters, $\bar{p}$ is the long-term average precipitation of the station, and SD is the standard deviation of precipitation. Fig. 3 shows the classification of the drought situation based on the SPI index. [16] The LST is drive from below formula: $\mathrm{LST} = \frac{T_b}{1+(L_\lambda * T_b + P) * Ln\varepsilon}$ (2)

In this formula $L\lambda$ scattered wave length radiance, T_b brightness temperature radiation power and P value is calculated from this formula:

$$P = h * c/(1.438 * 10^{2} m.\ ) \qquad (3)$$

That h is Planc factor (6.626*10^{-34} J.S), σ Estephan Boltezman factor (1.38*10^{-23}J/K),c is speed of light (2.998*108 m/s).

NDVI that is Normalized Difference Vegetation Index is known as one of the most famous, simplest and most practical plant indices [14]. The normalized difference vegetation index is expressed as follows:

$$\mathrm{NDVI} = \frac{\mathrm{NIR+RED}}{\mathrm{NIR-RED}} \qquad (4)$$

That NIR is near infrared band and RED is the red band values. This index has values between +1 and -1. The usual range of changes in green vegetation is equal to 0.2 to 0.8 (Tucker, 1997). The value of NDVI index is usually between 0.05 and 0.1 for sparse vegetation areas, and between 0.1 and 0.6 for normal and semi-dense vegetation areas. And for very dense plant areas, it is between 0.6 and 0.7. [17]

VCI is the Vegetation Condition Index, The amount of vegetation on the surface of the earth is basically determined by the main of the environmental Physical components such as climate and soil are controlled [18]. Purpose of VCI is identifying the effects of ecosystem change on vegetation in the region.

$$\mathrm{VCI} = \frac{\mathrm{NDVI} - \mathrm{NDVI_{MIN}}}{\mathrm{NDVI_{MAX}} - \mathrm{NDVI_{MIN}}} \; [19] \qquad (5)$$

TCI is Temperature Condition Index, that is assumed the phenomenon of drought causes a decrease in soil moisture and creates the heat stress will be on the earth's surface. The range of changes of this index is between 0 1. [20]

$$\mathrm{TCI} = \frac{\mathrm{LST_{MAX}} - \mathrm{LST}}{\mathrm{LST_{\,MAX}} - \mathrm{LST_{MIN}}} \qquad (6)$$

That LST_{min} and LST_{max} are the minimum and maximum temperature values in the time period. [21].

VHI index is a combined from VCI and TCI indices, the purpose of this index is, employing vegetation conditions and ground surface temperature in total index [21].

$$\mathrm{VHI} = (0.5 * \mathrm{VCI})\ (0.5 * \mathrm{TCI}) \qquad (7)$$

3. RESULTS AND DISCUSSION

In this paper our purpose is assessment the drought indicates using by remote sensing satellite imagery during 2015 to 2021 for central part of Natanz county and recognize the most appropriate indicate.

3.1 Processing Results

As mentioned in the definition of the SPI index, the input values of this index are the only factor of rainfall, and the purpose of creating the SPI index is to digitalize the analysis of the factor of rainfall, increasing positive values show a wet year indicate and decreasing negative values show more drought. As can be seen in the diagram, from 2015 to the end of 2019, despite the decrease, the values are positive, but their decrease in the period of 2019 to the end of the research period has even approached the number -2, which indicates a very severe drought situation.

According to Fig.4 the extent of areas with weak vegetation is increasing in the northwestern areas of the city, also in the central areas of the city and in the southwestern part, the growth of areas with weak vegetation can be seen, and also in the southwestern region in 2015, 2016 and 2017, the vegetation pattern is same and generally no vegetation was seen, but in 2018, 2019 and 2020, the vegetation slightly improved and grew towards the areas with weak coverage and higher NDVI values.

But in 2021, it can be seen that the loss of weak vegetation and NDVI is less than the previous years.

According to Fig. 5, for study area using the TCI index, toward 2015 in 2016 and 2017, an increase in severe drought areas is shown, especially in the southwestern, but in 2018, in the central and western, the drought situation improved and even some part of the region appeared without drought, while in 2019 there was a sharp decrease in drought-free areas and an increase in mild drought areas, in 2020 and 2021 toward 2019, by checking the index in the central areas according to the classification, the situation can be seen to improve.

Table 1. VCI value range

Class	Very High	High	Almost high	Mean	Normal
VCI	<10	<20	<30	<40	40>

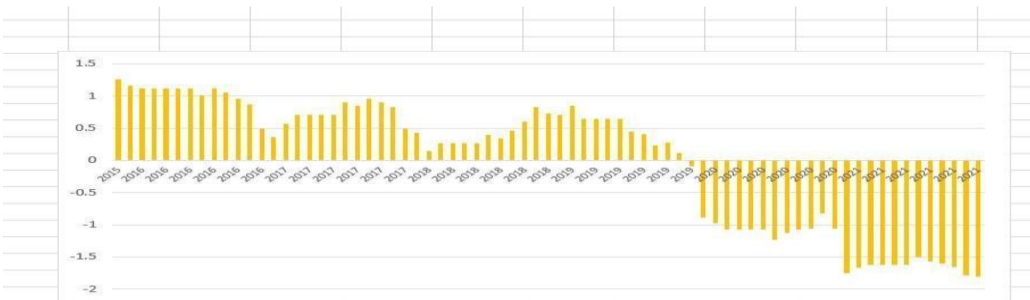

Fig. 3. Monthly average of synoptic station data during 2015 – 2021(mm)

According to the survey based on the VHI index, in 2016 and 2017 compared to 2015, an increase in the extent of areas with very severe drought can be seen in the southwest region, and in 2019, compared to 2018, there has been an improvement in the areas without drought and severe drought, but in the southwest region, severe drought has increased, a strong trend and by 2020 is shown, the drought situation in this area is getting worse. It can be seen in 2021 increase and decrease of areas with severe drought in the south and southeast regions, therefore, same as the previous indicators, the conclusion needs to match the maps produced with the numerical values obtained from the formulas and the standard deviation.

In 2016, compared to 2015, can be seen an improvement in drought situation, in 2017 southwest of this area drought is increased toward 2016.although In 2018, 2019, 2020 same pattern is shown but in 2021 drought situation has become much worse. According to SPI graph, the decreasing trend can be seen Better in the VCI index obtained maps.

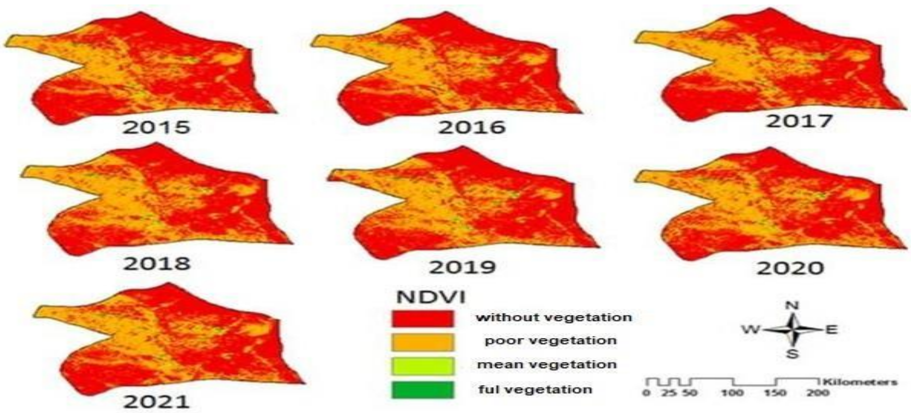

Fig. 4. The Normalized Deference Vegetation Index (NDVI) during 2015 – 2021

Table 2. TCI values

	2015	2016	2017	2018	2019	2020	2021
Mean	0.95	0.903	0.39	0.877	0.73	1.05	0.8
Standard deviation	0.60	0.59	0.62	0.39	0.691	0.84	0.695

Table 3. VCI index

	2015	2016	2017	2018	2019	2020	2021
Mean	39.178	31.52	48.48	29.98	33.102	28.55	21.3
Standard deviation	0.137	0.2575	0.388	0.28	0.2234	0.24	0.212

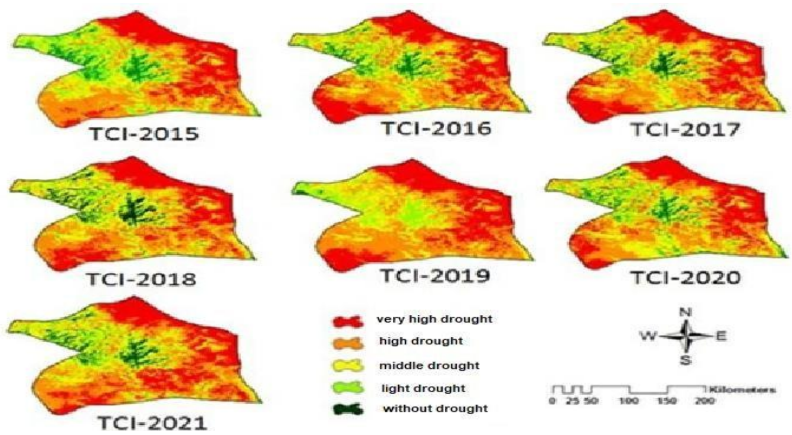

Fig. 5. Temperature Condition Index during (TCI) 2015 – 2021

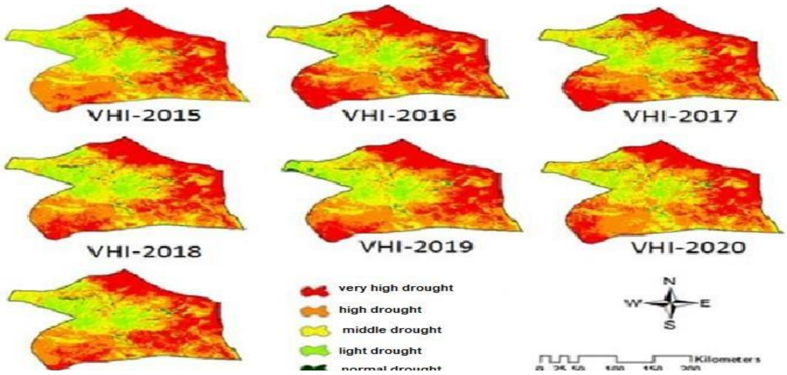

Fig. 6. Vegetation Health Index (VHI) during 2015-2021

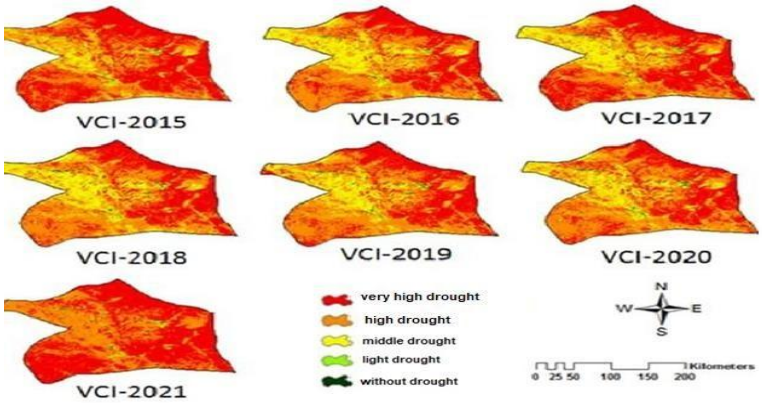

Fig. 7. Vegetation Condition Index (VCI) during 2015-2021

Table 4. VHI index

	2015	2016	2017	2018	2019	2020	2021
Mean	20.05	16.25	20.44	14.43	17.08	14.82	11.08
Standard deviation	0.33	0.32	0.34	0.32	0.33	0.44	0.37

3.2 Numerical Review Tables of the Above Indicators

According to the correlation between the standard deviation values of all three indicators, the correctness of the results is validated by acceptable values that is depended to the accuracy of the Sentinel satellite images.

4. CONCLUSION

In this paper assessment of drought indicates using sentinel satellite high resolution images has been done during 2015 to 2021 at Natanz county by remote sensing methods that is appropriate technique for drought monitoring in new studies. At first step the NDVI has been estimated and vegetation maps extracted the results show that the studied area has poor land vegetation. According to purpose of this research the land surface temperature (LST) has been calculated and three indicates VCI, TCI, VHI which are related to both of these arrival data (LST and NDVI) has choose [22,23]. All results demonstrated an increase of drought .According to the purpose indicates drought classified to very high, high, middle, light and without drought classes. The Vegetation Conditional Index (VCI) has the highest correlation with the results of the Ground-depended data methods, obtained by using meteorological parameters and the Standard Precipitation Index (SPI). The annual rainfall in 2021 is very low. On the other hand, the drought situation obtained from this index in 2021 has also been associated with an increase in the amount of drought in the southwest and northwest regions. Also, in the examination of the numerical values according to the definition of the drought index, when the number obtained from the formula is between 10 and 40, the drought conditions are increasing with the increasing trend of this value, which is exactly the same problem that can be seen in the linear representation of the index, so in this research, the best index for The assessment of the degree of drought is VCI. Among the calculated indices, VHI has the lowest correlation with the SPI index and, naturally, it has provided the weakest result. It should be noted that the NDVI and TCI indices show a relatively similar performance both in the generated maps and in the numerical values of the table and have a relatively good correlation with the SPI index. But the range of their changes does not show the changes made in the region as well as VCI.by use of this indicates, gives an ability to drought management, also use of this indicates duo to high spatial and temporal resolution can assist to making decisions in agriculture purposes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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