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REVIEW ARTICLE

Application of the Nighttime Light Remote Sensing Data for Urban Mapping in China During 2010-2022: A Comprehensive Review

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ABSTRACT

Using visible-band of night light emissions, it is now possible to observe human activity directly from space. This has made it possible to map urban areas, calculate GDP and population, and track conflicts and natural disasters, among many other things. More recently, night light satellite data from remotely detected night lights have been used to analyse the patterns, dynamics, and environmental effects of urbanization at various spatio-temporal scales. Yet, there is a lack of review papers in the topic on application of nighttime light (NTL) remote sensing for urban mapping and associated topics based on China. Thus, this study focused on two objectives; (i) evaluating the role of NTL data to urban mapping and monitoring, and (ii) exploring the efficiency of NTL remote sensing information for urban area monitoring. The present study shows that NTL data has a positive impact on urban mapping and urban area monitoring, especially in sub urbanization, and urban sprawl in China. The popularity of NTL data can be attributed to the facts that they reflect the socioeconomic status rather than impervious surface information that can be gleaned from optical remote sensing data, as well as the high temporal resolution. Additionally, after integrating NTL data with other optical remote sensing data, accuracy levels during micro level studies in urban areas can be increased. The free accessibility also affected to the usage of NTL data as China is still a developing country in the global south. The research also demonstrates that image calibration and other pre-processing techniques achieve high accuracy (>80%) when used with nighttime images. Different techniques are utilized to map urban areas, including threshold, segmentation, and regression analysis. But in recent times, machine learning techniques like random forest and cellular-automata are also are becoming popular. However, NTL still provide reliable and promising data sources for many applications and have the potential to make a greater contribution to the monitoring of urban areas in China.

1 Introduction

Urbanization is a complicated process and intensity of this process accelerate human activities in cities, including energy consumption and emissions (Fan et al., 2014). Especially in less developed countries, including China, the urban population will increase to 56.4% by 2030 (UN-DESA, 2018). Marking a milestone in urbanization history in China, out of the total population, 50% lived in cities by 2010. Most of the cities in China have urbanized rapidly during last three decade as a result of socio-economic and urbanization policies with creating several environmental and social issues (Withanage et al., 2023). Thus, it is mandatory to balance urban growth and environmental services provided by various ecosystems, especially in cities. Urban and regional planning authorities in China are now seeking sustainable solutions for those issues with reliable data including remote sensing (RS) data (Withanage and Jingwei, 2024). The advancement of the satellite remote sensing technology has fundamentally changed how we monitor the natural and manmade environment on the surface of the Earth and allows us to

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monitor wider areas (Jucker et al., 2017; Phiri et al., 2020). The scientific community has witnessed a number of images both paid (such as IKONOS, SPOT) and free access (like Sentinel, Landsat) merchant types with the launch of the first satellite allocated to assess the Earth surface (Landsat 1) on July 23, 1972 (Haack, 1982; Jucker et al., 2017). These sensors derive various remotely sensed information for many uses; including monitoring of cities, forests and natural disasters, and so on. Particularly in developing countries where financial resources are constrained, accessibility to non-paid remote sensing information (e.g., Landsat), has been playing a vital role in evaluating natural and manmade environment like urbanization (Haack, 1982; Turner et al., 2015).

The US Defense Meteorological Satellite Programme (DMSP) was established in the middle of the 1960s with the goal of gathering data on the world's cloud cover day and night. The Operational Linescan System (OLS), a second-generation low-light imager, was mounted on the DMSP Block 5D satellites, with the first launch occurring in 1976. Earth Observation Group (EOG) has been a pioneer in creating worldwide Nighttime Light (NTL) maps by fusing the images captured by DMSP-OLS since 1997. DMSP NTL is the largest information series available for nocturnal remote sensing on human functions, with annual data spanning from 1992 to 2013 (Elvidge et al., 1997). By 2019, 19 OLS devices have been flown in succession, and data gathering is still ongoing (Kyba et al., 2015). In order to meet the growing demand of socioeconomic activities, more and more artificial electric lights were built during the urbanization process (Chen et al., 2017). Human activity tends to increase with light intensity (Levin et al., 2020). Using visible-band nightlight emissions for remote sensing, it is now possible to see human activity directly from space, and is an important resource for area and world scale urban mapping and applications (Zhou et al., 2014). DMSP-OLS study the human activities through NTL information produced from DMSP/OLS sensors (Imhoff et al., 1997). NTL composite data is one of the most efficient data sources for extracting urban information. High temporal and spatial coverage satellite-based human induced NTL brightness information is an informative data source to analysis human functions and socioeconomic changes in the urban environment within the dynamic world (Ma et al., 2015). To extract urban impervious areas from the DMSP NTL data, several different urban mapping techniques have been suggested in literature (Imhoff et al., 1997). NPP-VIIRS also offers a significant amount of enhancements as per spatial resolution, temporal coverage, quantification, and calibrations. The increased spatial resolution allows for the observation of more radiance values in complex urban landscape (Elvidge et al., 2013).

Since NTL data have a strong correlation with socioeconomic indicators, and the density and height of built-up regions, it has been widely used to detect changes in socioeconomic and physical environments of cities. As an example, Ma et al.(2015) have cited that continuous satellite-generated observations of man-induced lighting signals at night give stable and effective proxy measures of population and socioeconomic trends in the urbanization process. This has made it possible to map urban areas, urban sprawl, sub urbanization, calculate GDP, CO_2 emissions, electricity consumption, and population, among many other applications (Chen et al., 2017). New research opportunities are also emerging with the development of new space generated, airborne, and terrestrial sensors for assessing light at night (Kyba et al., 2015).

In the recent past, China has experienced rapid urbanization as a result of different growth factors along with several socio-environmental issues. Major cities in China that have been rapidly urbanizing, have created different socioeconomic and environmental issues during the last three decade (Fan et al., 2014). Recent past has seen a marked increase in the rate of urbanization due to migration and the urban boundary expansion within the country. In this context, sustainable urban development requires maintaining a balance between human activities, the environment, population, and urbanization (Ma et al., 2015). In the EOG repository, NTL information from all stages can be accessed unpaid, similar to Landsat, Sentinel, and MODIS images (Phiri et al., 2020). As a result, this data have the potential to aid in urban monitoring around the globe, particularly in countries with limited financial resources.

The study presents a comprehensive review of the applicability of NTL RS data in urban mapping and monitoring across China during 2010-2020. With its advantageous characteristics, NTL data offer unique insights into urban mapping which may be overlooked by traditional RS data. The rapid pace of urbanization in China over the past decade has emerged the need of reliable and efficient data for urban area monitoring. While traditional RS data are also useful, they often face limitations in capturing nocturnal human activities and socioeconomic development patterns. However, NTL data capture artificial illumination from human activities. Due to the growing use of NTL data in urban research, a comprehensive understanding of how NTL data have been used across China can assist future researchers to enhance data integration strategies. Thus, this review is essential to consolidate existing knowledge, assess methodological advancements, evaluate the strengths and limitations of NTL applications, and identify emerging trends in urban mapping and monitoring within China from 2010 to 2022.

To the best of our knowledge, no such research reviews have been performed about the significance of NTL urban monitoring and related processes and phenomena within the Chinese context. The goals of this review are to (i) evaluate the role of NTL data in monitoring urbanization in China (2010-2022), and (ii) investigate the applications and potential of NTL data for urban mapping. New users of NTL data will find this review helpful, especially when contrasted to other free access data like Landsat, MODIS, and Sentinel.

2 Materials and Methods

Using techniques suggested by Blaschke (2010) and Ma et al. (2017), a systematic database search approach was used to discover literature in the ScienceDirect database. The techniques proposed by both scholars provided a solid foundation to developing a systematic data retrieval method for this review. Blaschke (2010) emphasized that the Object-Based Image Analysis (OBIA) enables more sophisticated database-driven analysis in RS which improves the thematic accuracy. Ma et al. (2017) proposed a structured literature review, searching scientific databases (eg: Scopus, Web of Science) with defined keywords such as “object-based classification,” “remote sensing,” and “land cover.” This ensured a comprehensive and reproducible selection of peer-reviewed studies. They analyzed and classified the papers based on: type of classifier (eg: SVM, Random Forest, Decision Trees); sensor type and resolution (eg: Landsat, Quick-Bird); application domain (eg: urban, forest, agriculture); and accuracy metrics used (eg: overall accuracy, Kappa). This literature search concentrated on studies on urban mapping and NTL. The Boolean operator (AND) was used to combine the search terms to look for specific NTL-related literature. Basic searches were conducted using the terms "nighttime lights" AND "urban mapping China”. More details of database search and documents retrieval, and step-wise procedure are illustrated in Fig.1 and Table 1.

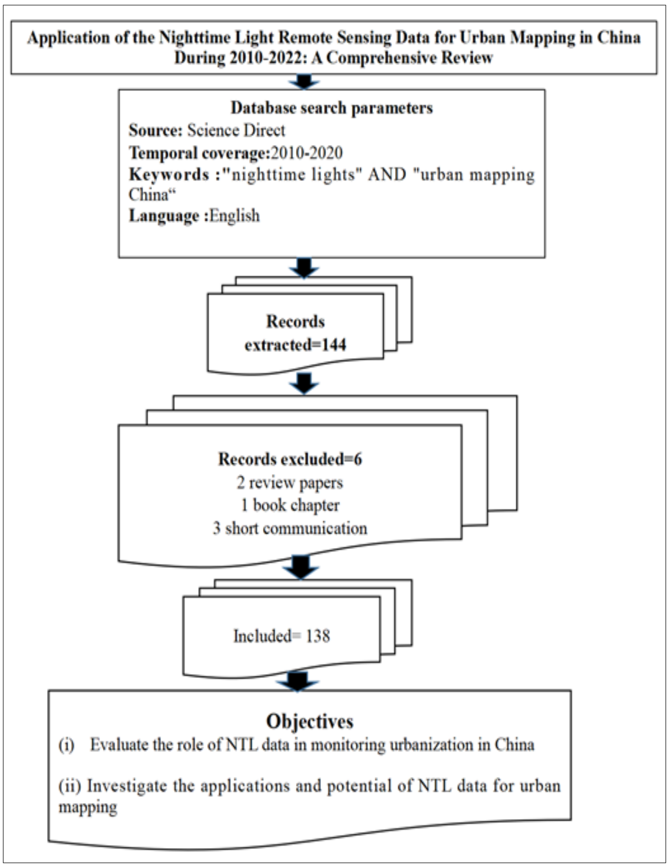

Fig. 1: Systematic flowchart of the review.

The list also did not include any research publication whose title, keywords or abstract lacked the desired search phrases. Due to time restrictions, only peer-reviewed articles that were published during 2010-2022 were taken into consideration in this study.

Table 1: The parameters used for the online literature search.

Parameter	Description
Keywords	"nighttime lights" AND "urban mapping China"
Type of document	Journal article
Language	English
Time period	2010-2022

3 Results and Discussion

A total of 144 documents resulted from the original literature search (Fig. 2). During the initial refinement, only research papers were taken into account. Thus, during the refining process, two review papers, one book chapter, and three short communications that contained the search clauses in the title, summary, and keywords disregarded, resulting in 138 research papers during 2010-2022. According to the results, most of the selected publications under the topic of interest were published after 2018.

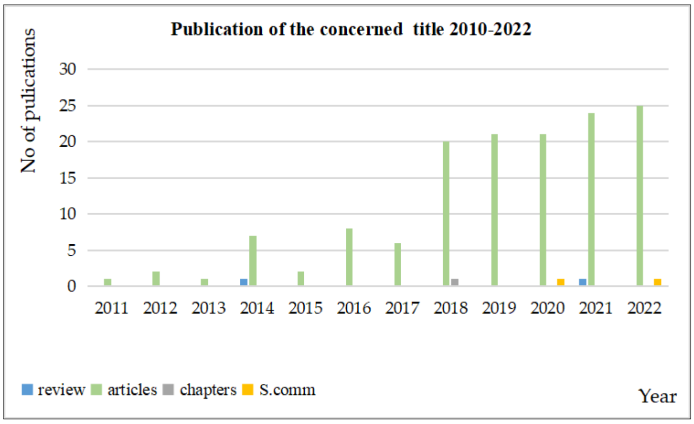

Fig. 2: Total publications under the key worlds of NTL and urban mapping in China during 2010-2022.

3.1 The Nature of the Review

About 49% of the available literature was from six journals including Remote Sensing of the Environment, Science of Total Environment, Journal of Cleaner Production, Ecological Indicators, Applied Geography, and Applied Energy. Other research publications (41%) were from journals like the International Journal of Applied Earth Observation and Geo-information, Energy, and Advances in Space Research. Of the 138 research papers, 97 articles (70%) were published in the subject area of environmental science, while 13% (19) of the research articles were published in open-access journals. When examining the subject distribution of articles, 37 manuscripts were published in environmental science, 31 in earth and planetary science, 29 in biological science, 12 in engineering, 7 in social sciences , and 22 in the other subject category.

3.2 Trends of Published Articles on NTL and Urban Mapping (2010-2022)

In the global context during 2010-2022, a total of 573 research articles were matched with the key terms "nighttime lights and urban mapping" (Fig. 3). Among them, 391 research papers appeared with "DMSP and urban mapping" while 478 papers were found searching with "VIIRS and urban mapping". DMSP and VIIRS both showed an increased trend in broad search without refinement. After the launch of the NASA-NOAA Suomi satellite's Visible Infrared Imaging Radiometer Suite (VIIRS) sensor in 2011, it was also utilized for different applications of the earth surface including urban mapping. Particularly starting in 2020, VIIRS typically had a higher number of publications for urban mapping compared to DMSP.

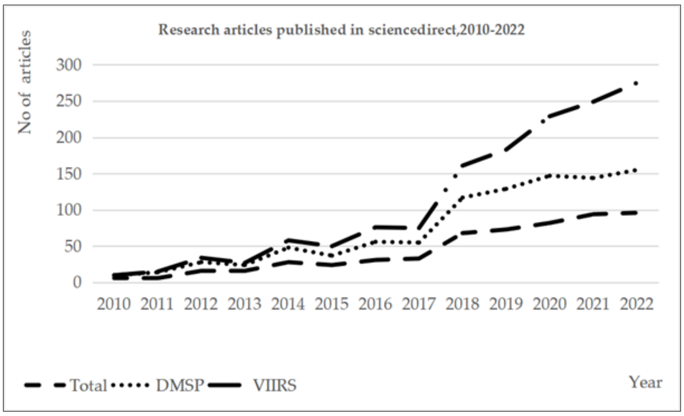

Fig. 3: The normal pattern of articles published from 2010 to 2022 based on the cumulative number of published papers.

These studies have concentrated on a variety of NTL and urban mapping issues, including urban growth, CO_2 emissions, electricity consumption, GDP, and other urban environmental applications like urban heat islands.

3.3 Overview of DMSP NTL Data

Since the 1962, satellite sensors maintained by the DMSP have been able to detect visible and near-infrared (VNIR) emissions from cities and towns. The DMSP OLS collects two spectral bands (VIS and TIR) of global daytime and nighttime images of the earth. From 1992, EOG has been a pioneer in creating worldwide NTL maps by fusing the images captured by DMSP-OLS. DMSP NTL is the longest data series available for nocturnal remote sensing on human activities, with annual average and background removed data spanning from 1992 to 2013. Since, the launch of DMSP NTL satellites in 1993, numerous urbanization-related research have been conducted in China (Levin et al., 2020). A satellite with Visible Infrared Imaging Radiometer Suite (VIIRS) that can detect nighttime sources of dim light, was launched in 2011 as part of the Suomi NPP (SNPP) mission (Imhoff et al., 1997). Additionally, EOG has suggested the cross-sensor calibration with convolutional neural network (CNN) as a solution for incompatible spatial resolution and dynamic range. From the VIIRS annual NTL composites, CNN creates NTL composites that resemble DMSP from 2013 onwards (Elvidge et al., 1999; Ghosh et al., 2021; Nechaev et al., 2021).

3.4 Urban Mapping with NTL Data

Though 138 articles were found under the topic of "Night time lights and urban mapping in China", only 18 research articles focused about urban growth and expansion directly (Table 2). Many cutting-edge techniques for urban area extraction from NTL data have already been developed since 2010 and 2022.

These techniques are based on the Digital Number (DN) values of NTL images. High computer capabilities has also aided in the development of DMSP-based urban mapping. The majority of techniques, such as random forests (RF), threshold, object-based segmentation, and statistical approaches, are dominated by machine learning techniques. The literature shows that most popular urban area mapping and extraction techniques are threshold, segmentation and regression, while threshold and segmentation are more frequently employed than the others. On the DMSP, advanced machine-learning methods like cellular automata (Wang et al., 2020; Wu et al., 2016) have also been applied. According to the literature, in most research work, DMSP-OLS information has been applied to monitor urban growth/dynamics. And for micro level city studies, some researchers have used Luojia 1-01 data sets individually or with DMSP. And few researchers used NPPP-VIIRS data for city size estimation, artificial surface, urban efficiency, and so on.

3.5 Image Pre-processing of NTL Data for Urban Mapping

Different image pre-processing techniques were used in earlier researches to enhance the consistency and comparability of DMSP NTL data. Zhang and Su (2016) carried out calibration and inter-calibration using second-order regression, an intra-annual composition, and an inter-annual series adjustment. Second order regression equations were used by Liu et al. (2021) to create inter calibrated yearly NTL pictures. Then using a shift-based approach, the inter-calibrated stable light image products were geometrically rectified. Following the recommendations made by earlier researchers (Elvidge et al., 1997; Wang et al., 2020), Huang et al. (2016) also employed calibration methods to eliminate blooming and over-saturation issues. Ma et al. (2015) used the second order regression method presented by Elvidge et al. (1999) to empirically inter-calibrate the annual NTL outputs in order to eliminate yearly changes and disparities among sensors.

Table 2: Details of previous studies directly addressing urban growth and expansion during 2010-2022.

Reference	Method/Approach	Objective	NTL Data Used
(Zhang and Su, 2016)	Regression analysis	Identifying urban expansion	DMSP-OLS SNTL
(Liu et al., 2012)	Random forest regression	Extracting urban floor area	LUOJIA 1-01 NTL
(Tong et al., 2018)	Threshold approaches	Identifying urban growth	DMSP-OLS- and NPP VIIRS
(Xu et al., 2022)	spatial auto correlation analysis	Quantifying urban vitality	LUOJIA 1-01 NTTL
(Yi et al., 2016)	Regression and threshold	Delimiting urban extents	DMSP-OLS SNTL
(Huang et al., 2021a)	Threshold approaches	Identifying urban expansion	DMSP-OLS
(Ma et al., 2012)	regression models	Quantifying urbanization	DMSP-OLS SNTL
(Huang et al., 2021b)	data fusion method	Mapping functional zones	JL1-07 NTL
(Hu et al., 2020)	object-based segmentation	Quantifying urban extent	DMSP-OLS
(Wu et al., 2016)	Night light urban efficiency index	Measuring urban efficiency	Suomi-NPP NTL
(Song et al., 2020)	Image segmentation and threshold	Measuring urban expansion and exposure to green space	DMSP-OLS NTL
(Yi et al., 2016)	Unit circle model and urban light index	Evaluating urban growth	DMSP-OLS NTL
(Chen et al., 2017)	NDVI threshold method	Spatio-temporal changes of green space	DMSP-OLS
(Sun et al., 2021)	Robust estimates	Estimating city size distribution	NPP/VIIRS
(Wang et al., 2020)	Random forest regression	Measuring relationship between NTL and artificial surface	NPP-VIIRS and Luojia 1-01
(Zhang and Su, 2016)	Multi-variable linear regression and variances partitioning	Measuring urban expansion	DMSP-OLS
(Ma et al., 2015)	spatially explicit threshold approach	Spatio-temporal dynamics of urban growth	DMSP-OLS
(Chen et al., 2017)	random forests-based cellular automata	Changes of urbanization	DMSP-OLS SNTL

Hu et al. (2020) used a filtering method to eliminate non-urban lights from NTL images that were found as clusters of illuminated spots in the desert and other non-urban areas, and produced a stable light mask.

3.6 Thresholds of NTL images

In most cases of urban and non-urban area extraction, researchers used threshold (Hu et al., 2020; Huang et al., 2016; Song et al., 2020; Yi et al., 2016; Zhang and Su, 2016) and image segmentation techniques (Liu et al., 2016; Ma et al., 2012). Hu et al. (2020) have used object based image segmentation. They employed a multi-resolution segmentation technique in order to maximize the heterogeneity among objects for a given resolution while minimizing the local heterogeneity of pixels inside the image object. Huang et al. (2016) have introduced an improved dynamic threshold method. Here, urban population and GDP data used with NTL to establish a yearly-continued and city-class-wide criterion for urban extent extraction. Through calibration, maximum DN values of images were increased from 63 to 78. The majority of the mean thresholds fell within the range of 30 and 50 of the DN values. According to Hu et al. (2020), the prefecture-level mean thresholds in DN value for urban patches ranged from 5 to 62. Urban areas along the coast typically have mean thresholds above 50. Greater thresholds are found in capital cities and the cities that surround them, with a brightness range of 40 to 55.

3.7 Regression Analysis

Regression analysis has been predominantly employed by scholars in research utilizing DMSP and VIIRS NTL data including Huang et al. (2016); Ma et al. (2015); Zhang and Su (2016). In order to determine whether there are any obvious trends in the time series of urbanization variables that might be related to temporal changes in NTL brightness, Ma et al. (2015) utilized the Mann-Kendall non-parametric test technique. Additionally, to qualitatively analyse the statistical relationship between NTL brightness and a number of synchronous urbanization factors, Spearman's rank correlation was used as another non-parametric method. In their research Zhang and Su (2016) used multivariate linear regression to identify the main determinants of urban growth in China during the focused time period. In this case, time-series of socioeconomic and natural variables were employed as independent variables, while the time-series urban land extent was used as the dependent variable.

3.8 Accuracy Assessment

Most DMSP and VIIRS based urban studies have derived comparatively higher overall accuracy for their urban land extraction. For example, Huang et al. (2016) have derived an overall accuracy (OA) close to 90%from the improved technique in each city class . The standard method's Kappa index and their index are similar, and both are higher than 0.3 (Ma et al., 2012). According to the findings f the study of Zhang and Su (2016), the producer's accuracy averages to 90.6% and ranges from 87.5% to 93.7% for the 30 larger cities. To assess the accuracy of the simulation results, classic CA models used the OA and Kappa metrics. However, prior research found that because a significant portion of the pixels are not transformed, Kappa and OA are not appropriate for use in large-scale images (Sun et al., 2021). Thus, Chen et al. (2017) introduced Figure of Merit (FoM) to assess the simulation results.

3.9 Implication and Future Outlook

The findings of the review have high potential and relevance of reliability assessment of NTL data for urban mapping in China. The DMSP have proven effective, by capturing capacity of human activities, urban sprawl than traditional optical RS data. The implications are profound for sustainable urban planning and policy formulation. This was enhanced through the high calibration techniques, and pre-processing methods. The integration of NTL data with other optical sources will enhance the micro-level reliability. Machine learning algorithms like RF and CA will offer new avenues for improved classification accuracy in complex urban areas. In future research, it is mandatory to refine image correction methods and develop hybrid approaches by integrating multiple data sources and algorithms. Additionally, limitations such as light contamination from non-urban sources (eg: gas flares, wildfires, and background noise) should be addressed to enhance the reliability in future research.

4 Conclusion

The purpose of this study was to comprehend how NTL data helped monitor urbanization in China. According to the most recent research, NTL data have the potential to be used for tracking urban growth throughout China. Numerous studies have also proved that NTL's data advantages over optical sensors like Landsat, and MODIS. For the extraction of urban areas and related applications, many techniques such as threshold, segmentation, and statistical regression methods have been used with NTL data. However, in more recent times, machine learning techniques like cellular automata and random forest methods have also been under intense scrutiny. According to the literature, the accuracy of extracted urban areas are comparatively higher in most cases and often exceed the level of optical remote sensing OA and Kappa results. To increase the accuracy of results, image calibration techniques have contributed more as image pre-processing. Thus, moving toward, NTL based urbanization monitoring for urban decision makers have more advantages than optical remote sensing since it also takes into the socioeconomic extent from night light data.

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Author Contributions

Conceptualization, methodology, analysis, writing, review and editing, N.C.W.. The author has read and agreed to the published version of the manuscript.

Conflict of Interest

The author declares no conflict of interest.

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