Urbanization monitoring using big Earth Observation data for world heritage sites of China

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Abstract. World heritage is a precious treasure left to mankind by history. It is a treasure of all human civilization and has very important historical, artistic and scientific value. Protecting world cultural heritage is a prerequisite for protecting the inheritance of human culture, safeguarding the diversity and creativity of the world's culture, and promoting the development of mankind. However, the rapid urbanization process globally has changed the land cover/land use, transportation and environmental conditions in cities, and has caused some impacts and damages to the world heritage sites. Based on three global Earth Observation datasets including Global Human Settlement Layer (GHSL), global population grid products (Worldpop) and the global night-time light images (DMSP/OLS), this paper proposed an urbanization intensity index (UII) to dynamically monitor and quantitatively assess the intensity of urbanization around the world heritage sites. Large UII values represent high urbanization degrees in the study area, and vice versa. The rapid increase of UII indicated that great impacts might be caused by the urban development process on corresponding heritage sites. The assessment results showed that the mean value of UII at 10 world cultural sites in China's urban areas increased from 0.35 in 2000 to 0.42 in 2015. The urbanization intensity index of the world cultural heritage sites can provide valuable datasets and scientific basis for the protection and development of world cultural heritage sites.

1. Introduction
World heritage refers to the rare and currently irreplaceable wealth recognized by United Nations Educational, Scientific and Cultural Organization (UNESCO) and the World Heritage Committee. It is a cultural heritage and natural landscape recognized by all human beings with outstanding significance and universal value. As of July 10, 2019, the total number of World Heritage sites reached 1,121, distributed in 167 countries around the world, including 39 world cultural and natural heritages, 213 world natural heritages, and 869 world cultural heritages.
The understanding of the relationships between human being and the land they live on is crucial to the achievement of sustainable development. World heritage site is a landmark or area as having cultural, historical, scientific or other form of significance, and is legally protected by international treaties. The urbanization process worldwide has led to a population shift from rural to urban areas and the expansion of urban areas in recent decades\(^1\). Global urbanization process has changed the land use, transportation and environment in cities, and caused impacts on world heritage sites \(^3\). Remote sensing data has been widely used to monitor the dynamics of urban expansion and urban land use changes \(^4\). The availability of big Earth observation datasets and products in recent years has made urban dynamics mapping and monitoring at large spatial scales possible \(^5\).

In this study, an Urbanization Intensity Index (UII) using multi-source Earth observation data and products was proposed to assess the impacts of human activities on world heritage sites. The intensity of human activities around the cultural heritage site (3KM buffer zone) provides the basis for the preservation and protection of World Heritage sites.

2. Study area and dataset

According to the official world heritage list of UNESCO in 2019\(^6\), China has 55 world heritage sites, including 14 natural heritage sites, 37 cultural heritage sites, and 4 natural and cultural heritage sites. The total number of heritage sites in China and Italy rank first in the world. We selected 10 world cultural heritage sites which are located in urban areas of China to assess the urbanization intensity in their surrounding areas (Figure 1). The 10 heritage sites include Summer Palace, Imperial Palaces in Beijing and Shenyang, Temple of Heaven, Potala Palace, Old Town of Lijiang, Ancient City of Ping Yao, Classical Garden of Suzhou, Yin Xu, Kulangsu, and Confucius Temple.

![Figure 1. Selected world cultural heritage sites in China.](image)

The multi-source Earth Observation data used in this study include the built-up area dataset of Global Human Settlement Layer (GHSL)\(^7\), the spatial demographic dataset of Worldpop\(^8\) and the global nighttime light imagery (DMSP/OLS)\(^9\). We acquired the three datasets in 2000 and 2015 to perform the assessment.

3. Methodology

The intensity of human activity can be measured using the extent to which human land use activities develop, utilize and transform the natural cover of the land surface. In this study, the land use, population density, and night-time light images were used conjunctively to obtain the Urbanization
Intensity Index (UII) to reflect the intensity of human activities of the surrounding areas of cultural heritage sites. The total workflow for UII estimation using Earth Observation datasets was illustrated in Figure 2.

Firstly, buffer zones with the distance of 500m, 1000m, 1500m, 2000m, 2500m and 3000m are delineated respectively using the geographic location data of world heritage sites [6]. The average value of the three datasets, namely population density, built-up area and night-time light index, were derived and normalized to the range of 0~1 in each buffer zone at the heritage sites.

\[ \text{UII} = \sqrt[3]{\frac{\text{BU}_{\text{nor}} \times \text{NTL}_{\text{nor}} \times \text{POP}_{\text{nor}}}{\text{BU}_{\text{nor}}}} \]

In the formula, BU_{nor}, NTL_{nor}, and POP_{nor} represent urban built-up area, night-time lights, and population data after normalization, respectively.

Finally, the UII values of each buffer zone are averaged to obtain the mean UII value at heritage sites in year 2000 and 2015, respectively.

4. Results and discussion
The UII values of the buffers of 500m, 1000m, 1500m, 2000m, 2500m, and 3000m in selected world cultural heritage sites in 2000 and 2015 were obtained (Figure 3-5). Different gradients of UII values were revealed in these sites. The increasing gradient of UII values indicated that the anthropogenic influences surrounding these sites became bigger, as it goes farther away from the center. The heritage sites shown in Figure 4 have the decreasing gradients of UII value. This indicated that the influences of human activities in these sites were decreasing as it gets farther from the center. For the heritage sites in Figure 5, the curve of UII values first increased and then decreased, indicating that the landscape patterns and land cover types are heterogenous near the heritage sites, which may be caused by the geographical backgrounds such as topographies.

Figure 3. Increasing UII gradients at world cultural heritage sites.
Figure 4. Decreasing UII gradients at world cultural heritage sites.

Figure 5. Varying UII gradients at world cultural heritage sites.

The UII values of each buffer were averaged to obtain the mean UII value in year 2000 and 2015 at the heritage sites. From Figure 6, it can be found that the UII values of the heritage sites in Beijing are higher than the UII values of other heritage sites. For heritage sites with high UII values, human activities in buffer areas are very intense which might lead to great impacts. The growth rates of UII for the heritage sites from 2000 to 2015 are compared in Figure 7. The changing rates in the heritage sites in Beijing are relatively low, although human activities are very frequent.

Figure 6. UII values at selected world cultural heritage sites in 2000 and 2015.

Figure 7. UII changing rates at selected world cultural heritage sites from 2000 to 2015.

In contrast, the growth rates of UII in areas with relatively small populations such as Suzhou Garden and Lijiang Ancient City are high. The growth rates of UII values in Suzhou Garden and
Lijiang Ancient City are 136% and 65%, respectively. The high-resolution satellite images of Lijiang and Pingyao Ancient City in 2000 and 2015 were acquired from Google Earth, as shown in Figure 8 and Figure 9, respectively. The croplands and water bodies were changed to built-up areas in the southeast part of Lijiang Ancient city. In Pingyao Ancient city, the small and scattered settlements were transformed to large and continuous built-up areas. Both cities experienced the process of built-up area expansion and urban development in last fifteen years, which has an agreement with the increasing UII values we derived in this study.

![Image](image_url)

**Figure 8.** High resolution satellite images of old town of Lijiang in 2000 and 2015.

![Image](image_url)

**Figure 9.** High resolution satellite images of ancient city of Pingyao in 2000 and 2015.

### 5. Conclusions

Based on our analysis, the Urbanization Intensity Index obtained from global big Earth Observation data including the Global Human Settlement Layer (GHSL), the Worldpop population data and global nighttime light images (DMSP/OLS) can reflect the intensity of human activities at world heritage sites in cities and towns. The results showed that the mean value of UII at 10 world cultural heritage sites in China increased from 0.35 in 2000 to 0.42 in 2015. High growth rates of UII values indicate that the urbanization process might have great impacts on the heritage sites. The proposed UII can be applied to heritage sites in other regions of the world, and thus provide scientific basis for the protection and development of world heritage sites.

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