Water colour from Sentinel-2 MSI data for monitoring large rivers: Yangtze and Danubes

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ABSTRACT

Rivers provide key ecosystem services that are inherently engineered and optimised to meet the strategic and economic needs of countries around the world. However, limited water quality records of a full river continuum hindered the understanding of how river systems response to the multiple stressors acting on them. This study highlights the use of Sentinel-2 MSI data to monitor changes in water colour in two optically complex river systems: the Yangtze and Danube using the Forel-Ule Index (FUI). The results revealed contrasting water colour patterns in the two rivers on both the spatial and seasonal scales. Spatially, the FUI of the Yangtze River gradually increased from the upper reaches to the lower reaches, while the FUI of Danube River declined in the lower reaches, which is possibly due to the sediment sink effect of the Iron Gate Dams. The regional FUI peaks and valleys observed in the two river systems have also shown to be related to the dams and hydropower stations along them. Seasonally, the variations of FUI in both systems can be attributed to the climate seasonality, especially precipitation in the basin and the water level. Moreover, land cover within the river basin was possibly a significant determinant of water colour, as higher levels of vegetation in the Danube basin were associated with lower FUI values, whereas higher FUI values and lower levels of vegetation were observed in the Yangtze system.

INTRODUCTION

Rivers are critical parts of global hydrology, and closely coupled with Earth's ecological and biogeochemical processes. However, the lack of consistent data of water quality over the length of rivers and the challenges with regards the collection of monitoring field data are well-recognised. The opportunity to unlock these challenges is only now possible with recent realisations in Earth observation and Big Earth Data cloud computing platform. However, the complex optical properties and water constituents of inland waters hinder the development of valid Earth observation for water quality of inland waters over large scales. Explicit spatial and temporal studies on inter-regional rivers remain to be very limited due to the contradiction of spatial resolution and spectral resolution of satellite data.

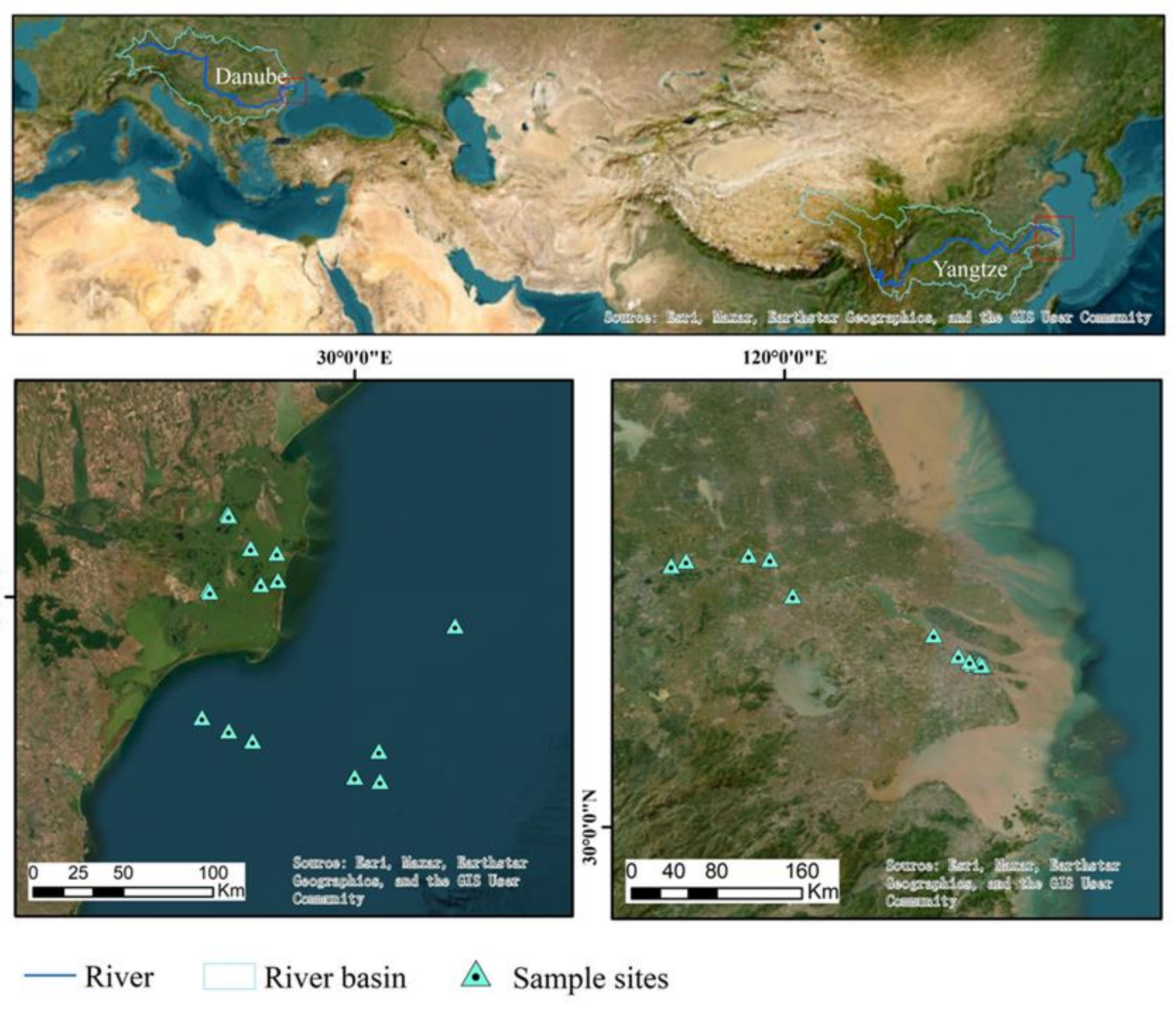
In this paper, the FUI was derived for the main channel of Yangtze and Danube rivers using Sentinel-2 MSI data during 2019-2021. For the first time, the spatial and seasonal patterns in water colour of the two rivers were analysed, and the influencing factors associated with the patterns were explored.

STUDY AREAS

Yangtze River has been a source of life and prosperity for the Chinese people for centuries and is a habitat for a remarkable variety of aquatic species.

Danube River flows through much of Central and Southeastern Europe, from the Black Forest in Germany into the Black Sea, and its drainage basin includes 19 countries in Europe.

Campaigns were conducted in the two rivers to collect in situ R_{rs} and water quality data.



METHODS

FUI in the 21 classes of water color was calculated based on the Sentinel-2 L2A surface reflectance data.

(1) CIE tristimulus X, Y, and Z were calculated:

$$X = 11.756R_{rs}(443) + 6.423R_{rs}(490) + 53.696R_{rs}(560) + 32.028R_{rs}(665) + 0.529R_{rs}(705)$$
$$Y = 1.744R_{rs}(443) + 22.289R_{rs}(490) + 65.702R_{rs}(560) + 16.808R_{rs}(665) + 0.192R_{rs}(705)$$
$$Z = 62.696R_{rs}(443) + 31.101R_{rs}(490) + 1.778R_{rs}(560) + 0.015R_{rs}(665) + 0.000R_{rs}(705)$$

(2) The chromaticity coordinates x and y were obtained:

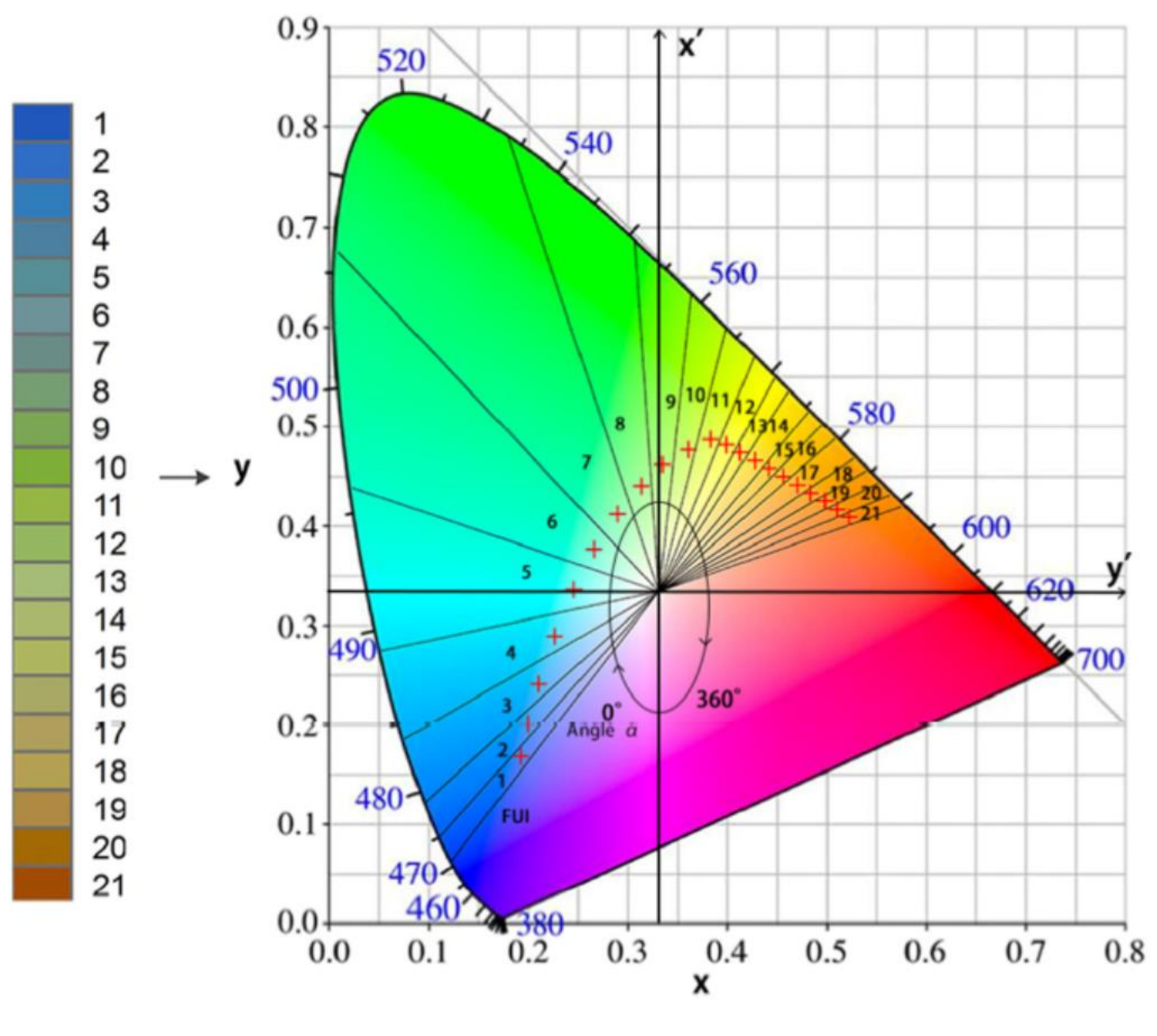
$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z}$$

(3) The hue angle α were obtained:

$$\alpha = (\arctan 2(y-1/3, x-1/3) \text{ modulus } 2\pi) * 180/\pi$$

(4) Delta (Δ) correction of hue angle for eliminating the colour difference caused by the visible band setting of Sentinel-2 MSI.

$$\Delta = -65.74*(\alpha/100)^5 + 477.16*(\alpha/100)^4 - 1279.99*(\alpha/100)^3 + 1524.96*(\alpha/100)^2 - 751.59*(\alpha/100) + 116.56$$



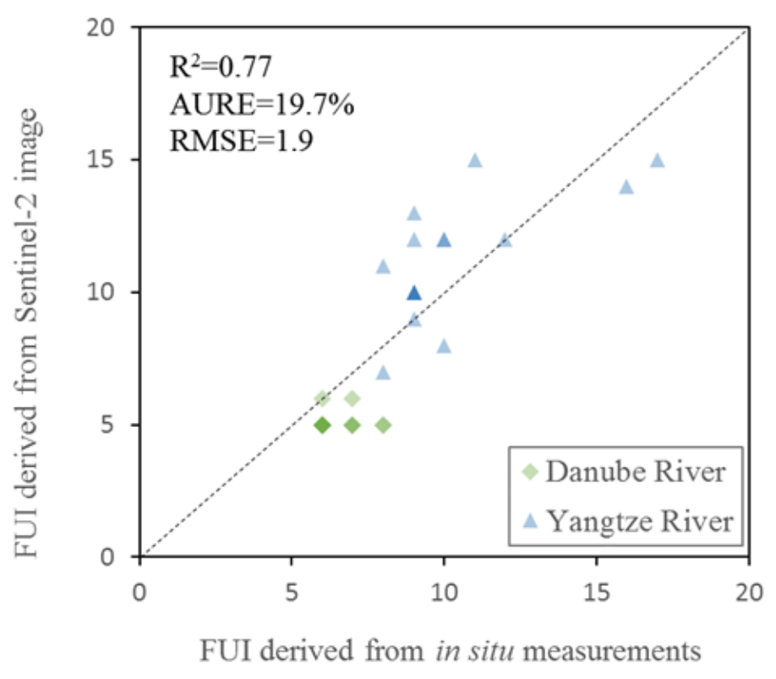
The 21-class FUI color table and its chromaticity coordinates in the CIE-xy diagram

(4) The FUI of each pixel can be derived with the corrected hue angle α using a FUI-hue angle look-up table (Wang et al., 2021).

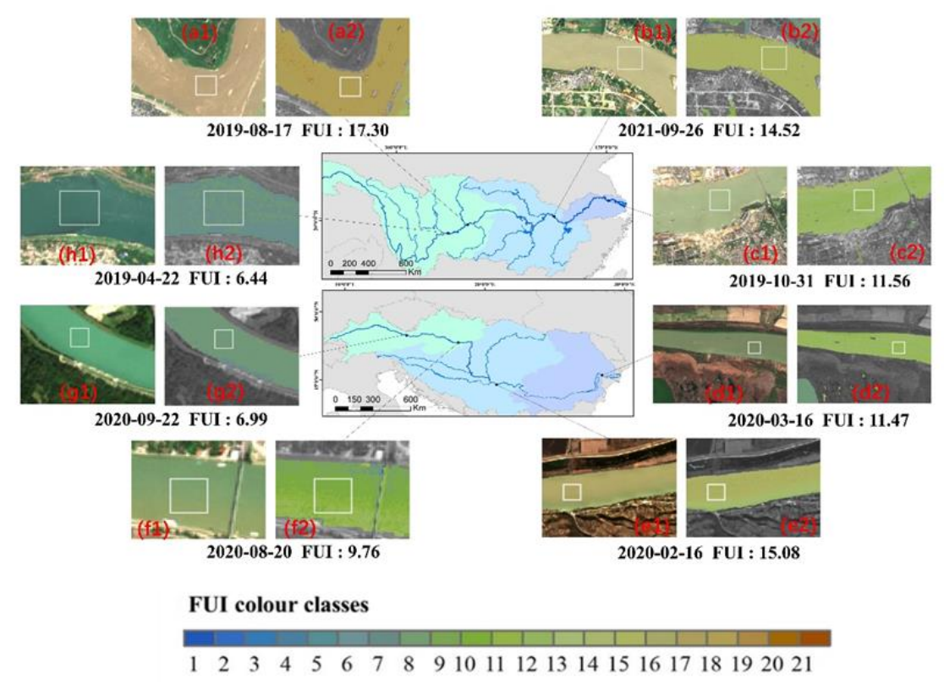
To analyze the spatial and seasonal variations of FUI in the two rivers, we applied the Mann-Whitney U non-parametric test to determine the differences of FUI among seasons and river reaches. The Mann-Kendall (MK) trend test method was employed to capture the changing trends of FUI through the rivers

RESULTS AND DISCUSSIONS

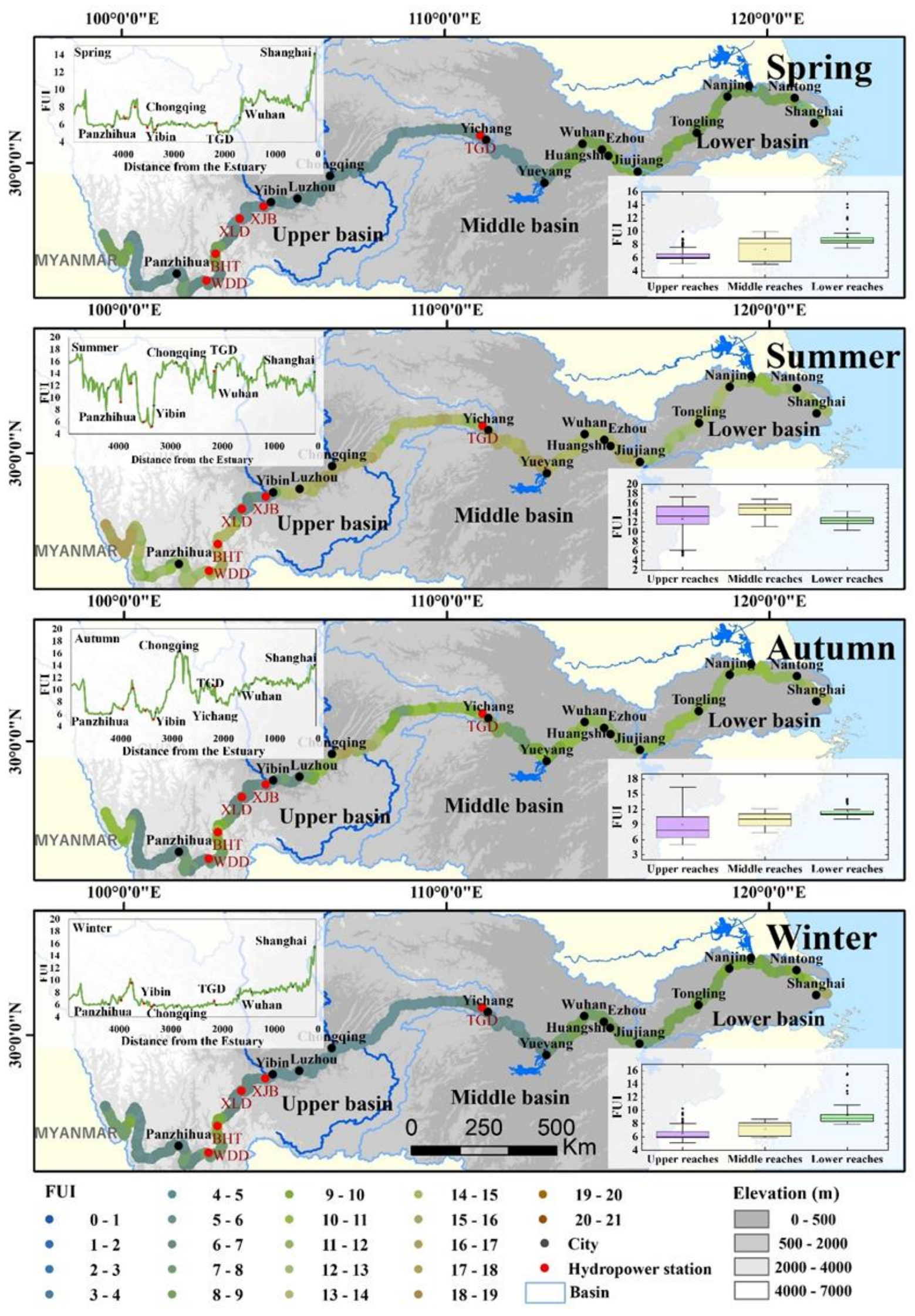
- The validation results with uncertainties of less than 20% confirmed the reliability of the developed FUI product using Sentinel-2 L2A data.



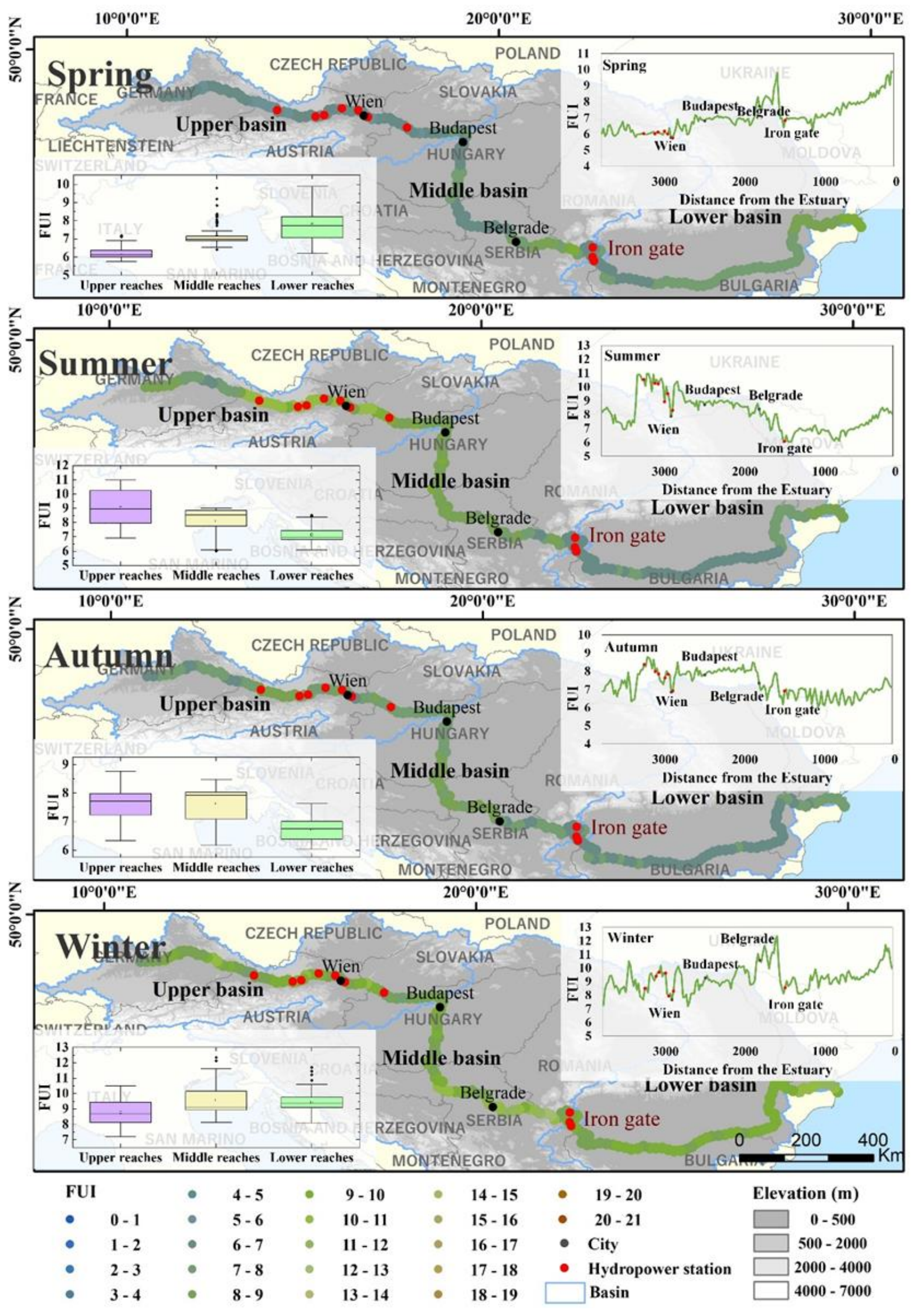
Scatterplots of FUI derived from in-situ measurements and from quasi-synchronous Sentinel-2 images.



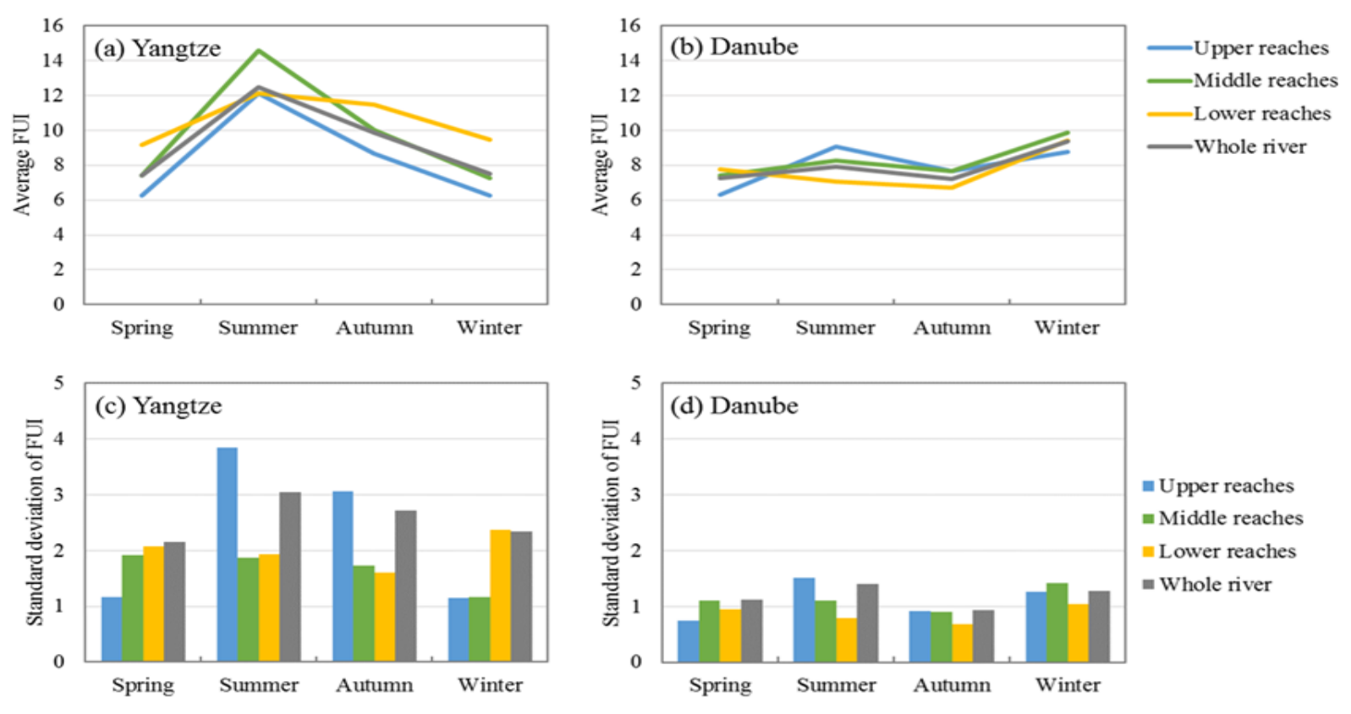
Comparison of the RGB-composited true color image (left) and the corresponding FUI color image (right) in Yangtze River and Danube River.



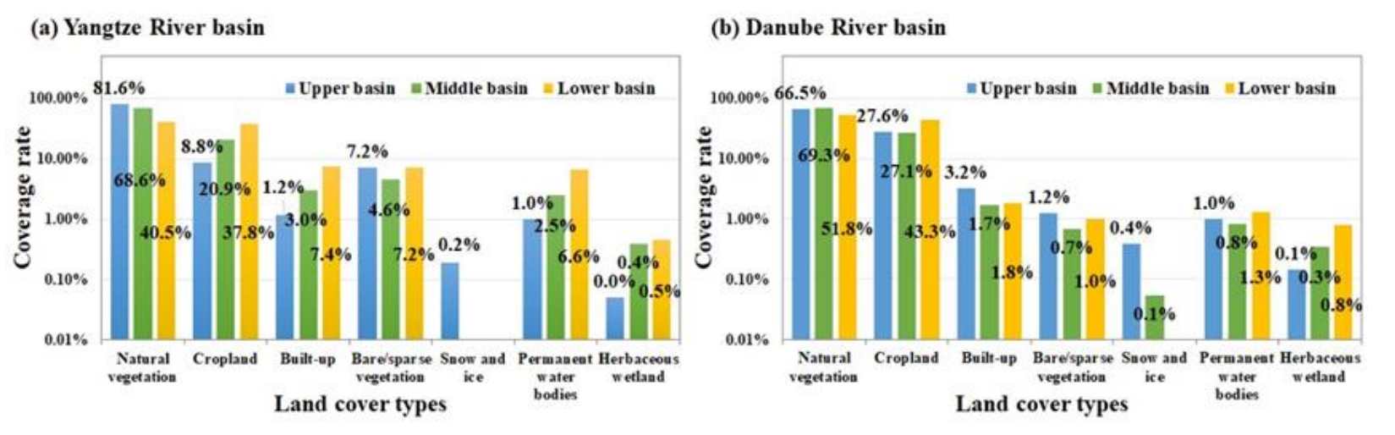
The FUI maps and statistics of Yangtze River in the four seasons during 2019-2021.



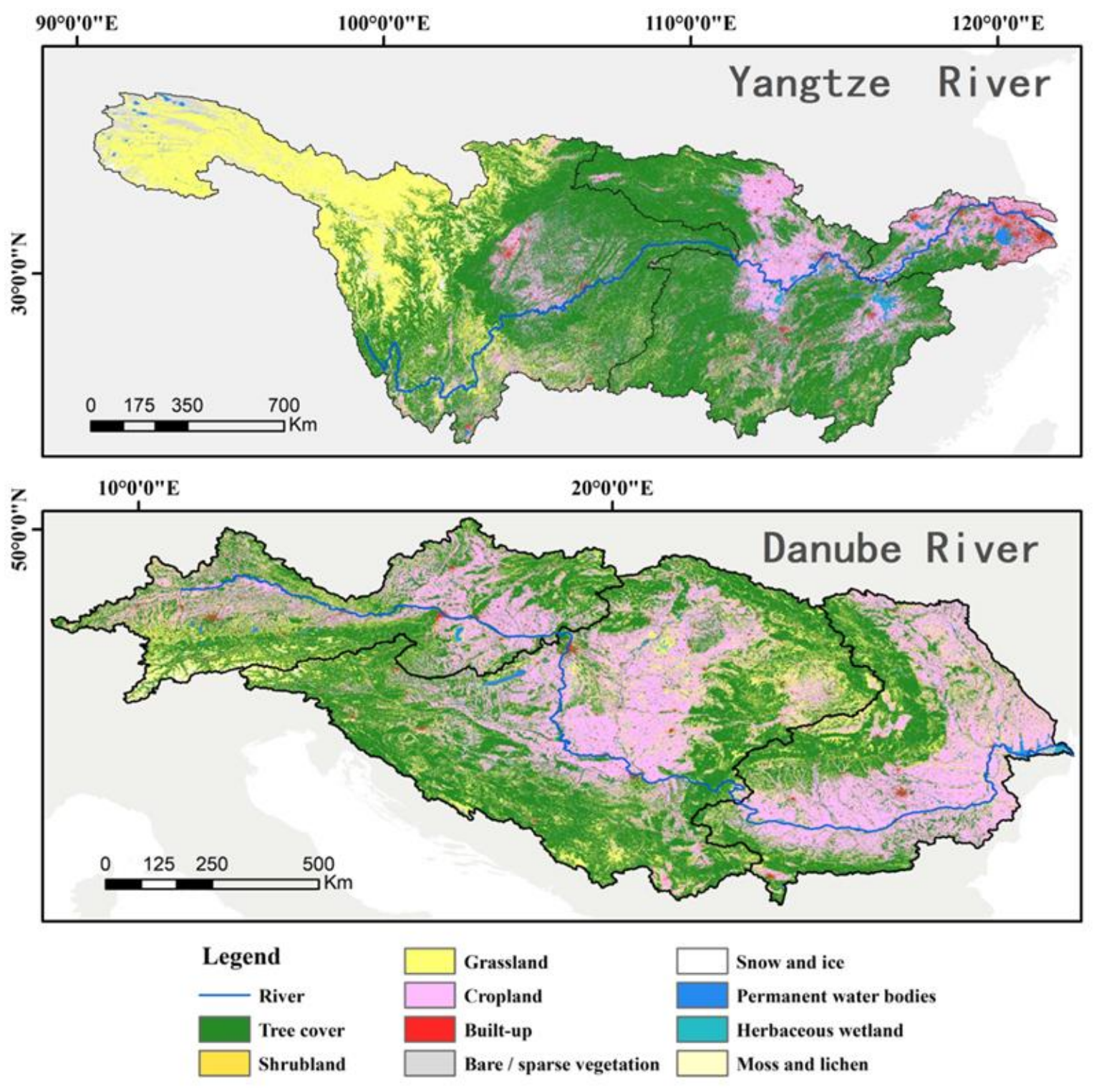
The FUI maps and statistics of Danube River in the four seasons during 2019-2021.



The seasonal variations of FUI in average value and standard deviation of the Yangtze and Danube rivers.



Statistics of the land cover rate of Yangtze and Danube river basins. The vegetation cover includes tree cover, shrubland, grassland and cropland.



Land cover maps in Yangtze and Danube river basins according to the ESA WorldCover 2020 product.

CONCLUSION

- Contrasting water colour patterns were observed in the two systems on both the spatial and seasonal.
- The land cover in the river basin may largely determine the water colour and turbidity in the river water.
- Dams and hydropower stations along both river systems and the spatial difference of precipitation have shown to contribute to spatial variations of FUI through impacting the sediment flux.
- High precipitation and floods during the wet season may disturb the river water resulting in the Yangtze being yellower and more turbid in summer and autumn and the Danube being yellower and more turbid in summer and winter.
- This study highlights the capacity of FUI, in rapidly quantifying and revealing the spatial variations and seasonality in river channels through the new generation of Earth observation data

MAJOR REFERENCES

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