Time Series Water Body Analysis Through Planet Satellite Imagery: A Coastal Urban Case Study

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ABSTRACT

Many water bodies play a crucial role as receiver of several urban basins within the water system of a city, these urban basins often face challenges of pollution and reduction in water flow, such as, the case of the Juan Angola channel in the city of Cartagena, Colombia. Current remote sensing strategies using Landsat and Sentinel-2 satellite imagery, lack the necessary spatial resolution to adequately study such as water bodies. In contrast, higher spatial resolution data, such as the PlanetScope one, allows for better spatial and temporal details. Nevertheless, PlanetScope does not count with the same spectral resolution as Landsat and Sentinel-2, requiring of further processings to extract relevant information. In this paper, we used PlanetScope satellite images, processed through computer vision techniques, to analyze the evolution of the Juan Angola channel, Laguna del Cabrero and Chambacú over time. Our approach involved extracting water areas from PlanetScope images and comparing these over different periods. Preliminary findings revealed noticeable variations in the area of the channel due to factors such as rainfall and possible illegal human invasion, as well as, the increment in level of contamination observed by means of the Normalized Difference Turbidity Index (NDTI). The images used from PlanetScope offered a more detailed time-series analysis of different hydrographic areas, which is particularly pertinent in the Juan Angola channel.

Keywords: Time series analysis, multispectral images, PlanetScope, computer vision, water channel, pollution.

1. INTRODUCTION

In recent decades, the emergence and evolution of remote sensing technologies have significantly transformed our ability to monitor and analyze Earth's surface and atmospheric phenomena. This advancement is particularly crucial for environmental studies in urban water bodies, which are increasingly subjected to anthropogenic pressures leading to degradation and pollution. The Master Plan for Stormwater Drainage of the District of Cartagena[1] highlights that Ciénaga de la Virgen and the Bay of Cartagena are among the primary water bodies constituting the hydrological system of Cartagena de Indias. These, along with the urban watersheds such as the Juan Angola channel, play a vital role in the ecological balance and urban water management of the region. Unfortunately, these areas face considerable challenges due to improper solid waste disposal, eutrophication processes, illegal encroachments, dumping of waste and sediments, and civil works that disrupt their flow, deteriorating water quality over time.[2,3]

The use of satellite imagery for Earth surface analysis has become an invaluable tool since the late 20th century, leveraging multispectral sensors to capture detailed environmental data.[4] Satellites have been providing such data since the 1970s, enabling studies on climatic variables, weather phenomena, and land cover changes. More recently, drones or unmanned aerial vehicles (UAVs) equipped with similar sensors have offered even greater spatial resolution, enhancing our capability to monitor specific areas in detail.[5,6] However, the use of drones for studying certain zones, including water bodies, can be limited by accessibility issues or regulatory restrictions,[7] such as those imposed by the Colombian Civil Aviation Authority (Aerocivil) which restrict drone operations near

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airports, including the area around the Juan Angola channel located near Cartagena's Rafael Núñez airport.[8] Other issues is related to the lack of temporal information that can help to monitor water bodies over time. Given these constraints, satellite imagery presents a viable alternative for environmental monitoring, despite some limitations in spatial resolution when compared to UAV-based imagery.[9] In this context, the choice of an appropriate satellite is crucial, with options like Landsat (30m) and Sentinel-2 (10m) often lacking the necessary spatial and temporal resolution for detailed studies of water bodies. This gap highlights the need for utilizing higher spatial resolution satellite imagery, such as that provided by PlanetScope satellites (3m), which, despite their lower spectral resolution compared to Landsat and Sentinel-2, offer superior spatial and temporal details essential for effective environmental monitoring.[10] This necessitates the application of advanced image processing techniques to fully exploit the available data.[11,12]

This paper aims to analyze the temporal evolution of the Juan Angola channel, Laguna del Cabrero, and Chambacú in Cartagena, Colombia, using high spatial resolution (HR) PlanetScope satellite imagery processed with computer vision techniques. Our methodology involves pre-processing images by making a radiometric correction, extracting water area data from these images using machine vision techniques with remote sensing indexes and finally conducting a time series analysis to assess changes over different periods. This approach is intended to address the gap in current remote sensing strategies, offering a detailed examination of the channel's condition and changes. Preliminary results, using the Normalized Difference Turbidity Index (NDTI), indicate a noticeable increase in the contamination level of the water body, underscoring the urgent need for targeted environmental management strategies.

2. METHOD

2.1 Remote Sensing: Landsat-8, Sentinel-2 and PlanetScope Satellites

Landsat-8, a product of the joint collaboration between NASA and the US Geological Survey (USGS), has been pivotal in Earth observation since its launch in 2013. It operates in the visible, near-infrared, and thermal infrared spectral bands, providing multispectral data with a spatial resolution ranging from 15 to 100 meters depending on the spectral band. This extensive coverage and moderate spatial resolution makes Landsat-8 particularly suitable for large-scale applications such as land cover classification, land use monitoring, and environmental change detection.[13,14] Similarly, the Sentinel-2 constellation, developed by the European Space Agency (ESA), comprises twin satellites, Sentinel-2A and Sentinel-2B, launched in 2015 and 2017, respectively. Sentinel-2 satellites offer multispectral imaging with 13 spectral bands ranging from the visible to shortwave infrared, and they operate at spatial resolutions varying from 10 to 60 meters. Like Landsat-8, Sentinel-2 provides global coverage and is widely used for applications such as agricultural monitoring, forestry management, and disaster mapping due to its high revisit frequency and spectral diversity.[15,16] In contrast, PlanetScope, operated by Planet Labs Inc., represents a newer generation of commercial Earth observation satellites. These small satellites are equipped with high-resolution cameras capable of capturing imagery at spatial resolutions as fine as 3 meters. While the coverage area of individual PlanetScope images is relatively smaller compared to Landsat-8 and Sentinel-2, the high spatial resolution of PlanetScope imagery makes it invaluable for detailed analyses of smaller areas such as urban environments, infrastructure monitoring, and precision agriculture.[17,18]

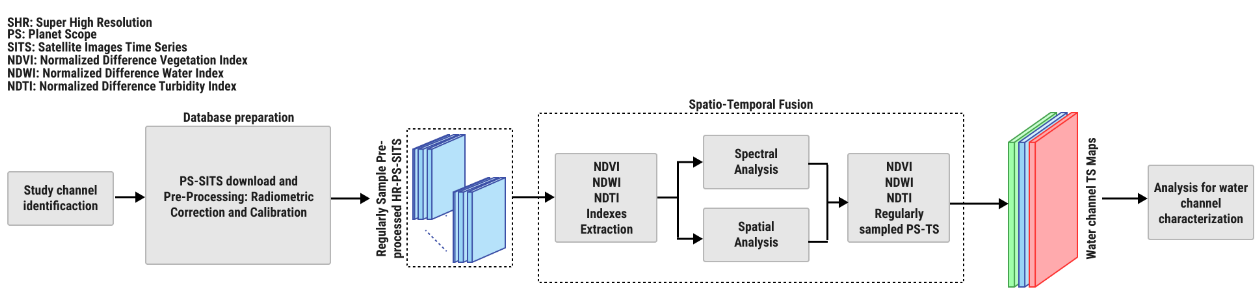


Figure 1. Three-stage workflow for processing and analyzing PlanetScope imagery via remote sensing index-based feature extraction.

The distinction in spatial resolution between Landsat-8, Sentinel-2, and PlanetScope satellites is a critical factor guiding our selection of imagery for this study. Landsat-8 and Sentinel-2 are commonly utilized for large-scale applications due to their wide coverage and moderate spatial resolution, whereas PlanetScope offers higher spatial resolution imagery that is particularly valuable for detailed analyses of smaller areas. This difference in resolution characteristics informs our choice of satellite imagery for the specific requirements of our research objectives. In order to show the methodology implemented, we created a three-stage workflow for processing and analyzing PlanetScope imagery via remote sensing index-based feature extraction as is shown in Fig. 1

2.2 Study Channel Identification and Database Preparation

Continuing with the methodology, the first stage involves delineating the study area and preparing the satellite imagery database. The chosen study area encompasses the Juan Angola channel, see Fig. 2, which originates in the Ciénaga de la Virgen, located immediately south of the Rafael Núñez Airport runway, and runs parallel to Avenida Santander, undergoing successive name changes as Laguna de Marbella, Cabrero, and Chambacú, before finally connecting via the Laguna de San Lázaro to the inner Bay of Cartagena. The Juan Angola channel spans approximately 4.12 kilometers in length, with a water surface area of around 10 hectares and an average depth of 2.76 meters.[19] The selection of this area is according to its significance as one of the water bodies of great relevance for the city. For this study, satellite images were acquired through the Planet satellite constellation (PlanetScope) due to its high spatiotemporal resolution, facilitating detailed and timely monitoring of environmental changes in the Juan Angola channel and the other water bodies.

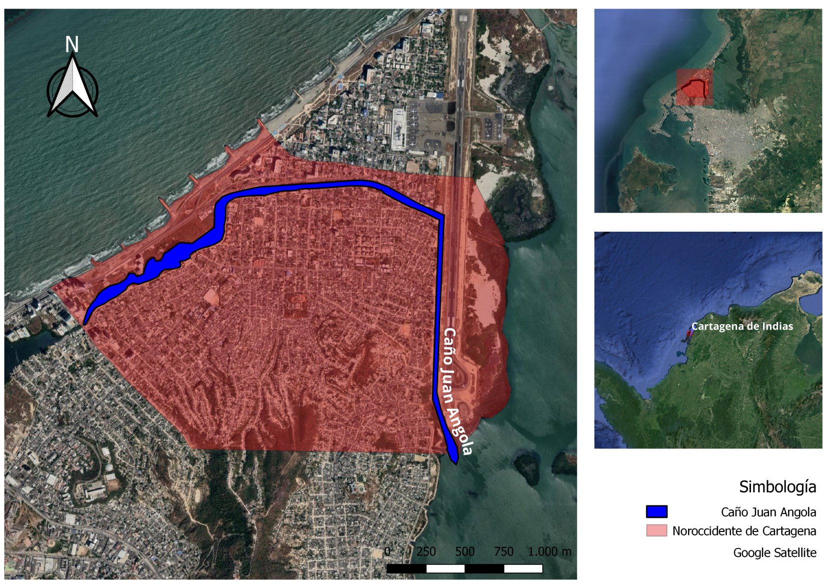


Figure 2. Study area encompassing the Juan Angola Channel, Laguna del Cabrero, and Chambacú in Cartagena, Colombia.

"PlanetScope" satellites have been in orbit since 2017, continually capturing multispectral images with a spatial resolution of 3 meters and featuring 8 multispectral bands since 2023 (Coastal blue, blue, Green I, Green, Yellow, Red, Red edge, NIR). These satellites acquire imagery with a sampling distance of 3.7 meters at a reference altitude of 475 kilometers, and the images are orthorectified to a pixel size of 3 meters. However, for this study, we considered the time series from January to May 2020, which coincides with periods before and after the onset of the COVID-19 pandemic. During this time frame, the captured images included only 4 bands: RGB + NIR. This time period also corresponds to part of the dry season transitioning into the rainy season. It is important to note that the selected time series is not continuous due to the manual selection of images through the Planet Explorer website, considering the absence of cloud cover obstructing the entire channel. This intermittent selection of images is referred to as Regularly Sampled PlanetScope Time Series. Additionally, some of the obtained images come with preprocessing, the diagram in Fig. 3 illustrates the path of how Planet delivers the images upon download. For this study, surface reflectance images are obtained, which come with sensor and radiometric calibrations, as well as orthorectification. Additionally, some images undergo radiometric enhancements, but not all. Therefore, preprocessing is required to match histograms and perform complete relative radiometric correction on all images, ensuring uniform pixel intensity ranges relative to a reference image. The selected reference image for this purpose was acquired on January 18, 2020. Typically, the reference image is chosen from the beginning or end of the time series.

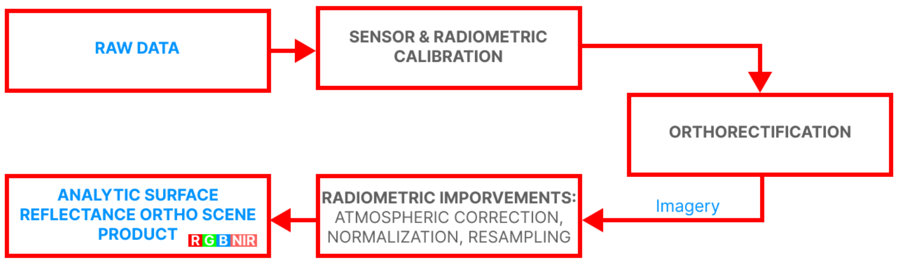


Figure 3. PlanetScope Processing Chain representing the process or stages generated on the website prior to the download of images with surface reflectance containing the RGB-NIR bands.

2.3 Processing and Spatio-Temporal Fusion

Once the image preprocessing is completed, the next step involves extracting features using remote sensing indices. These indices aid in delineating areas of interest or study, such as water bodies present in the image, which can be obtained using the Normalized Difference Water Index (NDWI).[20] Similarly, to assess the level of water contamination, the Normalized Difference Turbidity Index (NDTI) is derived.[21] These remote sensing indices are computed based on the relationship between the reflectance values of water bodies across the Red, Green, Blue (RGB), and Near-Infrared (NIR) bands of the electromagnetic spectrum captured by the spectral sensor of the PlanetScope satellite. Equation (1) and Equation (2) depict the relationships between the RGB and NIR bands utilized to compute the NDWI and NDTI remote sensing indices, respectively, as

$$NDWI = \frac{G - NIR}{G + NIR}, \tag{1}$$

$$NDWI = \frac{NIR - B}{NIR + B}. \tag{2}$$

At this stage, following the extraction of remote sensing indices for each pixel of the satellite image of the Juan Angola channel and its surroundings, the spectral analysis mentioned in the implemented method is related to the range of values of the NDWI and NDTI indices, which typically fall between -1 and 1. The closer the value is to 1, the higher the likelihood that the pixel in the image belongs to a water body. Based on literature, it is valid to consider a surface as having moisture or water from NDWI values of -0.2. However, higher negative NDWI values within the range may indicate the level of water contamination due to turbidity or suspended materials. Therefore, the closer the value is to 1, the higher the contamination or turbidity of the water. Similarly, for spatial analysis, the identification of water bodies is based on the NDWI index, which allows for the establishment of a threshold (set to -0.22 for this study) to identify areas considered as moist or containing water. This threshold enables image binarization, and subsequently, through processing techniques such as morphological operations and pixel area thresholding, image segmentation is performed to obtain a mask or image representing only the areas belonging to the Juan Angola channel, Laguna del Cabrero and Chambacú.

2.4 Time Series Maps Generation and Analysis

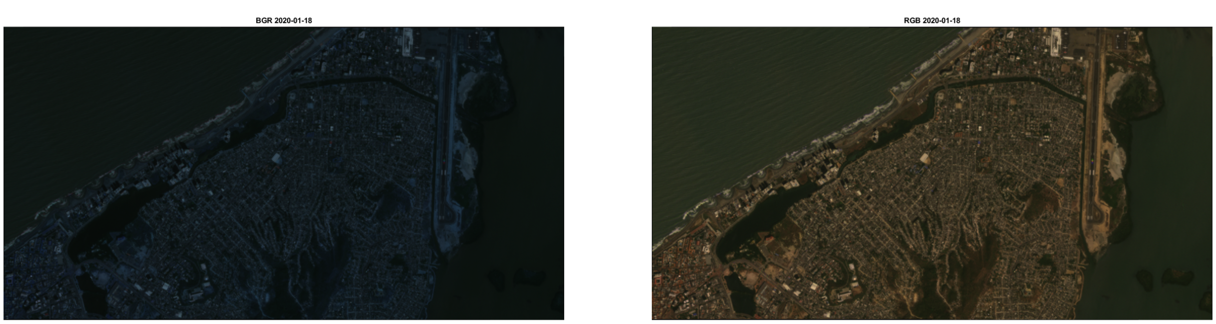
In the Time Series Maps Generation and Analysis section, we focus on the creation and examination of temporal maps derived from the remote sensing indices obtained for the Juan Angola channel. Utilizing the NDWI and NDTI indices computed for each pixel across a time series of PlanetScope satellite images from different periods between January and May 2020, encompassing periods both before and after the onset of the COVID-19 pandemic, we generate maps depicting the spatial distribution of water bodies and their contamination levels over time. This process involves aggregating the pixel-wise NDWI and NDTI values across multiple images spanning these different time periods, enabling the visualization of temporal variations in water presence and contamination within the study area. We also investigate changes in the water surface over time in terms of pixel count. This analysis targets certain segments of the water body belonging to the Juan Angola channel.

3. EXPERIMENT AND RESULTS

For this study, Regularly Sampled PlanetScope Time Series between the periods of January 18th to May 26th, 2020, taking advantage of the changes in human activity due to COVID-19, were selected. The objective is to validate the proposed method, as it would provide a better understanding of the changes in water bodies. Table 1 details the characteristics of the image acquired through the Planet satellite, and Fig. 4a illustrates an example of how Planet delivers the product. In this case, the image is delivered with the combination of all bands organized in the order BGR, necessitating a process of band reorganization into RGB format and radiometric correction through histogram matching as a preprocessing stage[22] as it is shown in Fig. 4b. Additionally, it is worth highlighting that the images were selected during the afternoon hours. This decision was made because the shadows cast by the buildings on the channel were minimized during this time period.

Table 1. Characteristics of the image obtained by the PlanetScope satellite

Image Characteristics	
Satellite	PlanetScope (Surface Reflectance)
Instrument type	Dove Classic (PS2)
Publishing Stage	Finalized
Cloud Cover	50%
Acquisition date	2020 (01/18, 02/02, 02/12, 02/23, 03/05, 03/23, 03/27, 04/06, 04/14, 05/15, 05/26)
Acquisition time	15:59h, 15:56h, 15:55h, 15:55h, 15:12h, 15:36h, 15:36h, 15:09h, 15:12h, 15:11h
Bands	BGR-NIR
Spatial Resolution	2.39m
Pixel Image Resolution	Clip of 889x1660 px from 4096 x 4096 px in the captured image by Planet sensor
Planet Processing	Atmospheric correction and geometric alignment



(a) (b)

Figure 4. PlanetScope image for January 18, 2020: (a) representation of the study area in BGR false color composition, and (b) reorganization of bands into RGB false color composition with the improvement of the image after performing radiometric correction using histogram matching.

In the processing stage, composed of Spatio-Temporal Fusion, remote sensing indexes based on the bands obtained from satellite images were extracted. Through manual observation, the lowest ranges obtained for water bodies were identified, as depicted in Fig. 5. Subsequently, a binarization threshold was established, enabling the generation of images like the example shown in Fig. 6a, where white pixels represent wet areas or potential water bodies present in the image, while black pixels represent non-water features such as vegetation, buildings, and others. This process facilitated the segmentation of water bodies belonging to the Juan Angola channel and other water bodies under study, distinguishing them from the Caribbean Sea and the Ciénaga de la Virgen. This procedure was repeated for each image acquired within the selected time period for the study, resulting in the generation of the Regularly Sampled PlanetScope Time Series for water bodies, as illustrated in Fig. 6b.

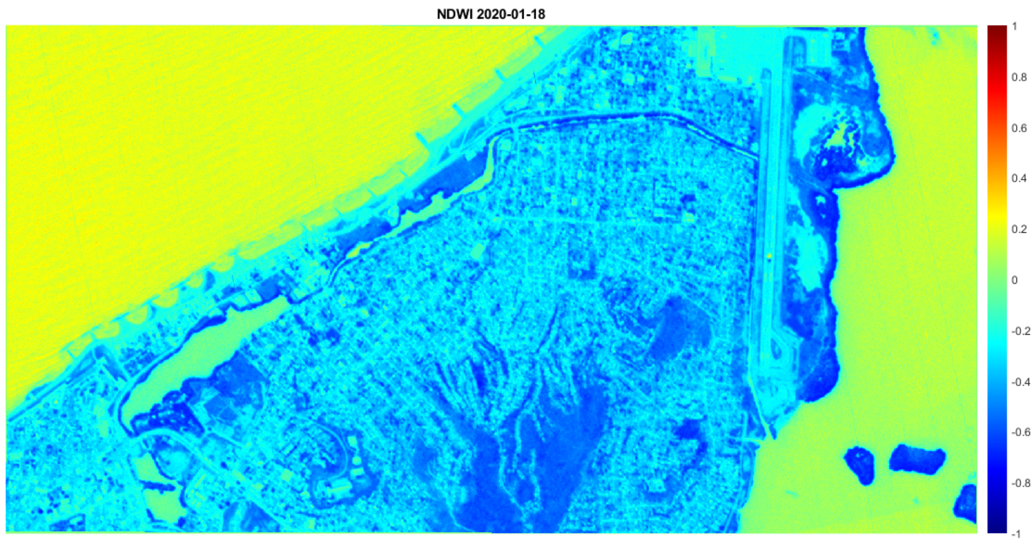


Figure 5. Heat map of the Normalized Difference Water Index values for the study area on January 18, 2020.

(a) (b)

Figure 6. (a) illustrates the binarization process using the configured threshold value of -0.22 for this study, and (b) depicts the segmentation process of only the areas of interest belonging to the studied water body.

Then, by computing the water area for each image in the time series, we generate a graph depicting the temporal evolution of the water area within the Juan Angola channel, see Fig. 7. This analysis complements the examination of remote sensing indices, providing a quantitative measure of changes in water extent over the study period. Similarly, the NDTI index extraction was conducted to highlight changes in water turbidity. Figure 8 displays the time series and the varying turbidity levels present in the water body.

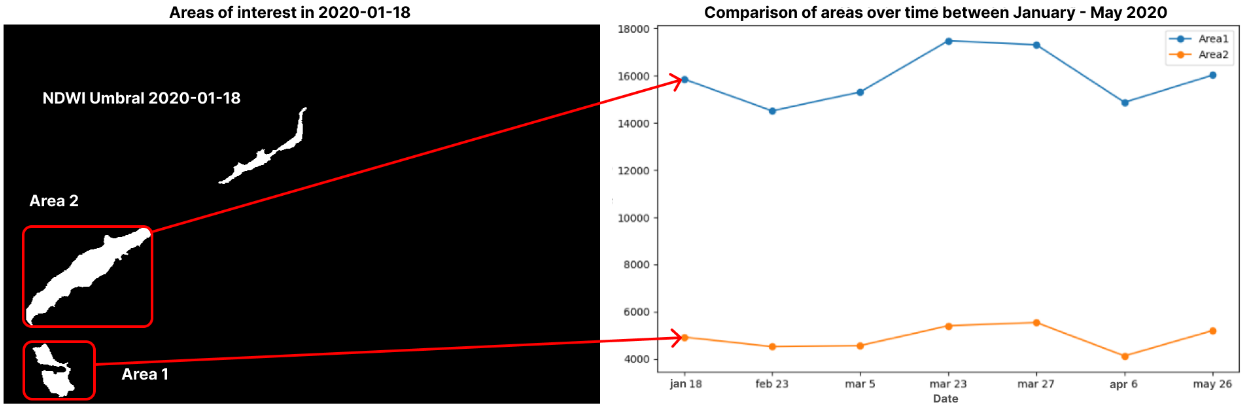


Figure 7. Graph depicting the temporal evolution of the water area within the Juan Angola channel, Laguna del Cabrero y Chambacú.

Figure 8. Heat map of the Normalized Difference Turbidity Index values for the study area on January 18, 2020.

4. CONCLUSIONS

This study demonstrates the effectiveness of utilizing PlanetScope satellite imagery in conjunction with computer vision techniques to analyze the temporal evolution of the Juan Angola channel. Through our approach of extracting water areas from these images and comparing them over different periods, we were able to discern notable changes in contamination levels, as evidenced by the Normalized Difference Turbidity Index (NDTI). This underscores the capability of remote sensing technologies to provide valuable insights into environmental dynamics, particularly in assessing water quality and contamination trends. It is essential to highlight that the Juan Angola channel is predominantly surrounded by vegetation such as trees and shrubs, which obstructs clear visibility of the channel and complicates analysis in those areas. However, it can be assumed that the conditions observed in analyzed zones may be representative of those in inaccessible areas. This assumption is based on the continuous flow throughout the entire channel and the presence of in-situ studies measuring contamination levels and factors affecting the channel. For future works, it will consider employing statistical and geospatial analysis or DataScience techniques, together with weather information, to analyze these time series maps, identifying trends, patterns, and anomalies in the dynamics of the Juan Angola channel. This study not only contributes to the field of geospatial informatics by demonstrating the application of HR satellite imagery for water quality monitoring, but also highlights the potential of such technologies in supporting sustainable urban and environmental planning in regions facing similar challenges.

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