Flood Analysis Using Remote Sensing Techniques: A Case Study in Valencia, Spain

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Abstract

In June 2024, Valencia, Spain, faced severe flooding caused by a **Dana (Depresión Aislada en Niveles Altos)**, resulting in extensive damage to infrastructure, urban areas, and agriculture. This study uses Sentinel-2 and Sentinel-1 satellite imagery with Google Earth Engine to assess the flood's impact through advanced remote sensing techniques, including cloud masking, histogram matching, and pansharpening. Key changes in vegetation, water bodies, and urban areas were identified using spectral indices such as NDVI, NDWI, and NDBI. The analysis highlights the utility of satellite data and cloud-based tools for rapid, cost-effective flood mapping and disaster management.

1. Introduction

Flooding is a destructive natural disaster that causes extensive damage to infrastructure, agriculture, and human livelihoods. Valencia, Spain, is highly susceptible to flooding due to its Mediterranean climate and geographical features. In June 2024, the region experienced severe flooding caused by a **Dana (Depresión Aislada en Niveles Altos)**, a high-altitude depression that resulted in intense rainfall over three days. This event led to widespread damage to urban areas, transportation networks, and agricultural lands, emphasizing the need for effective flood mapping and impact assessment tools.

Satellite-based remote sensing provides a rapid, large-scale, and cost-effective alternative to traditional ground-based flood assessments. This study leverages **Sentinel-2 and Sentinel-1 imagery** and Google Earth Engine (GEE) to analyze the spatial extent and environmental impacts of the Valencia flood. Using techniques like cloud masking, histogram matching, pansharpening, and spectral index analysis (NDVI, NDWI, and NDBI), the study identifies key flood-induced changes in vegetation, water bodies, and urban areas. These findings aim to support disaster management strategies and improve future flood mitigation efforts.

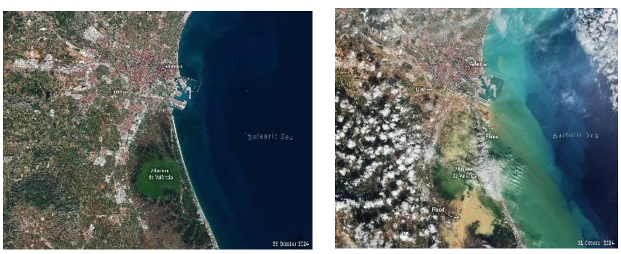

Image 1. Pre and Post Flooding Sentinel 2 Imagery

2. Methodology

2.1 Study Area

The study focuses on Valencia, Spain, a region prone to seasonal flooding due to its Mediterranean climate and proximity to major water bodies. Flooding in this area often leads to significant environmental and infrastructural damage. The Region of Interest defined was Valencia Town with coordinates: [-0.392, 39.518], [-0.392, 39.390], [-0.297, 39.390], [-0.297, 39.518], [-0.392, 39.518]

2.2 Data Sources

This study employs satellite imagery from Sentinel-2 and Sentinel-1 to achieve comprehensive flood analysis.

Sentinel-2 Multispectral Imagery:

Sentinel-2 provides high-resolution optical data (10–20 meters) with multiple spectral bands.

Its **Near-Infrared (NIR)** and **Shortwave Infrared (SWIR)** bands are particularly useful for detecting water and vegetation changes.

Its ability to collect data across multiple wavelengths enables the calculation of spectral indices like NDVI, NDWI, and NDBI, which provide key insights into environmental and infrastructural impacts.

Sentinel-1 Synthetic Aperture Radar (SAR):

Sentinel-1 data is less affected by weather conditions like clouds or rain, making it indispensable for flood monitoring during extreme weather events.

SAR captures the texture and structure of flooded regions, providing an additional layer of information, particularly in urban areas. These complementary datasets allow to cross-validate findings and overcome the limitations of individual sensors.

2.3 Image Preprocessing

Accurate preprocessing is necessary to ensure high-quality and reliable data for analysis. The following preprocessing steps were applied in Python coding with Jupyter Lab.

Cloud Masking:

Sentinel-2 imagery is often obstructed by clouds and their shadows, especially during flood events when weather conditions are unfavorable.

By using the **Scene Classification Layer (SCL)** from Sentinel-2, we removed cloud and shadow pixels, ensuring that only valid surface features are retained for analysis.

Histogram Matching:

Histogram matching was performed to align the spectral properties of pre- and post-flood images, particularly for the Near-Infrared (NIR) band.

This step ensures that changes detected in spectral indices like NDVI or NDWI, are not caused by sensor differences or environmental factors unrelated to the flood.

Pansharpening:

Sentinel-2 RGB bands (B4, B3, B2) have a spatial resolution of 10 meters, which is adequate but not optimal for detailed visualizations.

To enhance spatial resolution, the RGB bands were **pansharpened** using the NIR band (B8), which has higher spatial detail.

Resampling:

Sentinel-1 SAR data, which operates at a resolution of 10 meters, was resampled to align with Sentinel-2 imagery.

2.4 Spectral Indices

Spectral indices are mathematical combinations of spectral bands that highlight specific features such as vegetation health, water bodies, or urban areas. The indices used in this study include:

Normalized Difference Vegetation Index (NDVI):

NDVI is widely used to monitor vegetation health and density. Healthy vegetation reflects more NIR light and less red light, resulting in higher NDVI values.

Normalized Difference Water Index (NDWI):

NDWI enhances the visibility of water features by taking advantage of the strong absorption of NIR light by water.

Normalized Difference Built-Up Index (NDBI):

NDBI highlights built-up areas, such as roads, buildings, and infrastructure, which typically reflect more SWIR light and less NIR light.

2.5 Change Detection

To evaluate flood impacts, the difference between pre- and post-flood spectral indices was calculated:

NDVI Difference:

By subtracting pre-flood NDVI values from post-flood values, areas where vegetation health decreased, likely due to flood-related damage, were identified.

NDWI Difference:

The increase in NDWI values indicates areas that experienced water expansion, effectively mapping the extent of flooding.

NDBI Difference:

Changes in NDBI values reveal disruptions to urban areas, such as water pooling on roads or near buildings.

2.6 Masked Visualizations

To focus on key findings, masked visualizations were created:

NDWI Increase Mask:

Areas where NDWI values increased (NDWI > 0) were isolated and displayed on the map. This highlights only the flood-affected regions, making it easier to visualize the extent of water encroachment without distraction from unchanged areas. (Can be appreciated in Figure 3)

2.7 Digital Elevation Model, Buildings and Roads Incorporation to Analysis

Digital Elevation Model was applied to the map as well as roads obtained from Overpass Turbo. On the other hand, using supervised classification with random forest method in QGIS Semi-Authomatic Classification tool, the building's infrastructure was determined and saved as raster.

3. Results

3.1 Pre- and Post-Flood Analysis

- Pre-Flood Imagery: A clear representation of the study area before the flood, highlighting the distribution of vegetation, water bodies, and urban areas.
- Post-Flood Imagery: The extent of water coverage and changes in vegetation post-flood were evident. Urban areas and vegetation showed noticeable impacts from the flood event (Figure 1).

Figure 1. Post-Flood Image

3.2 Pansharpened Imagery

The pansharpened imagery demonstrated improved spatial detail for RGB visualization, aiding in identifying subtle flood impacts. The increased spatial resolution enabled better detection of water pooling and changes in urban and vegetated areas (Figure 2).

Figure 2. Pansharpened Imagery

3.3 Vegetation and Water Index Differences

- **NDVI Difference:**
  - The NDVI difference map revealed a decrease in vegetation health and coverage, with the pre-flood NDVI area measured at 14.36 km^2 and the post-flood NDVI area at 14.04 km^2.
  - The NDVI area change was -0.32 km^2, constituting a -0.27% decrease relative to the total ROI area. This indicates minor vegetation stress and inundation.
- **NDWI Difference:**
  - The NDWI analysis showed minimal changes in water body extent, with the pre-flood NDWI area measured at 4.24 km^2 and the post-flood NDWI area at 4.18 km^2.
- **NDBI Difference:**
  - The NDBI difference map revealed the most significant impact, particularly in urban areas. The pre-flood NDBI area was 5.68 km^2, while the post-flood NDBI area dropped to 4.78 km^2.
  - The NDBI area change was -0.90 km^2, amounting to a -0.77% decrease relative to the total ROI area. This highlights

substantial urban inundation and infrastructure disruption.

3.4 Digital Elevation Model (DEM) Integration

The DEM analysis showed that the most flood-affected areas were located in low-lying regions, particularly near water bodies and riverbanks. These regions corresponded with areas of increased NDWI and decreased NDVI, validating the spectral index-based findings.

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4. Discussion and Conclusion

4.1 Discussion

Flood Analysis Results

Metric	Value
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Total Area of ROI (km^2)	116.09075431508244
NDVI Pre-Flood Area (km^2)	14.35534104274565
NDVI Post-Flood Area (km^2)	14.038524363809618
NDWI Pre-Flood Area (km^2)	4.240517761966586
NDWI Post-Flood Area (km^2)	4.178728272657948
NDBI Pre-Flood Area (km^2)	5.678620420769274
NDBI Post-Flood Area (km^2)	4.780648899508967

The results of this study illustrate the spatial extent and environmental impacts of the June 2024 flood in Valencia, Spain, using advanced remote sensing techniques. By integrating Sentinel-2 and Sentinel-1 satellite imagery with spectral index analysis, the study provided valuable insights into the flood's effects on vegetation, water bodies, and urban areas.

1. **Vegetation (NDVI Analysis):**
   - The -0.27% decrease in NDVI indicates limited damage to vegetation, likely due to temporary waterlogging and stress caused by inundation. This aligns with the flood's short duration and Valencia's resilient vegetation, which is adapted to Mediterranean climate fluctuations.
   - Most vegetation appears to have remained intact, suggesting that the flood's impact on agriculture may be less severe than initially anticipated.
2. **Water Bodies (NDWI Analysis):**
   - The -0.05% decrease in NDWI indicates effective natural drainage and minimal long-term changes to water bodies. This finding suggests that the floodwaters receded quickly, reducing the likelihood of prolonged flooding or waterlogging.
   - The areas showing increased NDWI values (highlighted in the NDWI increase mask) corresponded to low-lying regions near rivers and water channels, emphasizing the importance of hydrological planning in these zones.
3. **Urban Areas (NDBI Analysis):**
   - The -0.77% decrease in NDBI represents the most significant change among all indices. This reduction highlights the vulnerability of urban infrastructure to flooding, particularly in areas with inadequate drainage or flood defenses.
   - The analysis revealed temporary water pooling in roads and built-up areas, which could disrupt transportation networks and exacerbate economic losses.
4. **Validation with DEM:**
   - The DEM analysis confirmed that low-lying areas were the most affected, validating the spectral index findings. Roads and buildings located in these areas showed significant changes in NDBI and NDWI values, indicating that urban infrastructure in these zones is highly susceptible to flood impacts.

Figure 3. Flood Analysis

4.2 Conclusion

The flood analysis in Valencia, Spain, provides critical insights into the environmental and infrastructural impacts of the June 2024 flood event. The study demonstrates the utility of remote sensing and cloud-based tools like Google Earth Engine for rapid, cost-effective flood assessment. By observing Figure 3 we can effectively determine the areas that where affected, aligning all the data making it coherent.

4.3 Recommendations

1. **Urban Planning and Resilience:**
   - Improve drainage systems in urban areas, especially in low-lying zones identified as high-risk in the DEM analysis.
   - Develop flood-resilient infrastructure, such as elevated roads and reinforced buildings, to mitigate future impacts.
2. **Vegetation Monitoring and Recovery:**
   - Conduct follow-up assessments to monitor vegetation recovery and identify areas requiring intervention, such as replanting or soil restoration.
3. **Hydrological Planning:**
   - Use the NDWI and DEM findings to prioritize flood defense measures, such as embankments and river channel modifications, in the most flood-prone areas.
4. **Future Research:**
   - Integrate socio-economic data to assess the flood's broader impact on livelihoods and economic activity.
   - Validate remote sensing findings with ground truth data for enhanced accuracy.

This study underscores the importance of remote sensing in flood management and supports data-driven decision-making for disaster mitigation and recovery efforts in Valencia and similar flood-prone regions.

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