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Comparative analysis between spectral indices obtained in the *Guangüiltagua* metropolitan park in Quito – Ecuador, using remote sensing

Análise comparativa entre índices espectrais obtidos no parque metropolitano Guangüiltagua em Quito – Equador, utilizando sensoriamento remoto

Análisis comparativo entre índices espectrales obtenidos en el parque metropolitano Guangüiltagua en Quito – Ecuador, mediante teledetección

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The research aids in ecosystem management by providing insights into vegetation cover and potential water stress conditions. This represents a potential methodological innovation applicable to other scenarios of developing countries or countries with environmental sustainability problems.

ABSTRACT

The article presents an exhaustive comparative analysis of NDVI, SAVI and NDWI spectral indices, extracted from satellite images of the Guangüiltagua Metropolitan Park in Quito. The relevance of remote sensing, using satellites such as Sentinel-2, in the monitoring of biodiversity and environmental conditions is highlighted. The research emphasizes the importance of vegetation indices, especially NDVI, to assess vegetation health and detect changes in vegetation cover. The study discusses in detail vegetation sensitivity, water identification, water stress response, soil effect compensation and specific applications of NDVI, SAVI and NDWI. The ability of these indices to provide crucial information on ecosystem health, water presence, and potential water stress conditions in Metropolitan Park is highlighted. The methodology applied involves the use of the Copernicus platform and the Sentinel-2 satellite, with radiometric and geometric correction procedures, as well as atmospheric correction. The results obtained reveal high NDVI values, indicating a dense vegetation cover, while NDWI suggests potential areas of water scarcity. The comparative analysis between the indices offers a deeper understanding of the relationship between vegetation and water in the park.

Keywords: Remote Sensing, Spectral Indices, Plant Health, Water Stress.

RESUMO

O artigo apresenta uma análise comparativa exaustiva dos índices espectrais NDVI, SAVI e NDWI, extraídos de imagens de satélite do Parque Metropolitano Guangüiltagua, em Quito. É destacada a relevância da deteção remota, utilizando satélites como o Sentinel-2, na monitorização da biodiversidade e das condições ambientais. A pesquisa enfatiza a importância dos índices de vegetação, especialmente o NDVI, para avaliar a saúde das plantas e detectar alterações na cobertura vegetal. O estudo discute detalhadamente a sensibilidade da vegetação, identificação da água, resposta ao estresse hídrico, compensação do efeito do solo e aplicações específicas de NDVI, SAVI e NDWI. Destaca-se a capacidade destes índices em fornecer informações cruciais sobre a saúde do ecossistema, a presença de água e possíveis condições de estresse hídrico no Parque Metropolitano. A metodologia aplicada envolve a utilização da plataforma Copernicus e do satélite Sentinel-2, com procedimentos de correção radiométrica e geométrica, além de correção atmosférica. Os resultados obtidos revelam valores elevados de NDVI, indicando cobertura vegetal densa, enquanto o NDWI sugere potenciais áreas de escassez de água. A análise comparativa entre os índices oferece uma compreensão mais profunda da relação entre vegetação e água no parque.

Palavras-chave: Sensoriamento Remoto, Índices Espectrais, Fitossanidade, Estresse Hídrico.

RESUMEN

El artículo presenta un exhaustivo análisis comparativo de los índices espectrales NDVI, SAVI y NDWI, extraídos de imágenes satelitales del Parque Metropolitano Guangüiltagua en Quito. Se destaca la relevancia de la teledetección, utilizando satélites como Sentinel-2, en el monitoreo de la biodiversidad y condiciones ambientales. La investigación enfatiza la importancia de los índices de vegetación, especialmente el NDVI, para evaluar la salud vegetal y detectar cambios en la cobertura vegetal. El estudio aborda detalladamente la sensibilidad a la vegetación, la identificación de agua, la respuesta al estrés hídrico, la compensación del efecto del suelo y las aplicaciones específicas de NDVI, SAVI y NDWI. Se resalta la capacidad de estos índices para proporcionar información crucial sobre la salud del ecosistema, la presencia de agua y posibles condiciones de estrés hídrico en el Parque Metropolitano. La metodología aplicada involucra el uso de la plataforma Copernicus y el satélite Sentinel-2, con procedimientos de corrección radiométrica y geométrica, así como la corrección atmosférica. Los resultados obtenidos revelan valores elevados de NDVI, indicando una cobertura vegetal densa, mientras que NDWI sugiere áreas potenciales de escasez de agua. El análisis comparativo entre los índices ofrece una comprensión más profunda de la relación entre vegetación y agua en el parque.

Palabras clave: Teledetección, Índices Espectrales, Salud Vegetal, Estrés Hídrico.

INTRODUCTION

Remote sensing allows obtaining information from the earth by means of sensors located on satellites. It is an important tool for analyzing what is happening on the earth's surface, and today it is widely used in environmental studies in which biodiversity, deforestation and fires, among others, are monitored (Cabello and Paruelo, 2008).

The earth's surface presents different structures such as vegetation, water bodies, areas without vegetation, which capture solar radiation, which is sometimes reflected or absorbed, depending on the intensity of this and the different wavelengths captured, either by moisture, by the formation of the earth based on different minerals, this makes spectral signals that are emitted to satellites and valuable information is obtained for the different analyses required (Romero, 2016).

There are a number of satellites that are emitting this type of information, depending on their capacity and their degree of resolution, among these we have:

Landsat 8, MODIS, VIIRS, Sentinel-2, Ikonos, AVHRR, SPOT-7, ENVISAT, JERS, NOAA, ORBVIEW, among others.

A spectral index is a parameter calculated as a function of reflectance values at different wavelengths, it can also be described as a number resulting from the combination of spectral bands, among these are the vegetation indices that are related to the proportion of vegetation present in a given pixel. Vegetative vigor can be estimated from these vegetation indices, allowing to highlight those areas where plants have a high photosynthetic activity (Avila and Royero, 2021).

The index analysis reveals a connection between NDWI and NDVI, since NDWI highlights water in the vegetation. The higher the NDWI values, the higher the NDVI, indicating more vegetation. In the comparison with SAVI, the latter shows higher values, thanks to its ability to reduce the influence of soil reflectance on the image. This explains the higher values in SAVI compared to NDVI (Montenegro D, 2016).

The NDVI index estimates the photosynthetic process through the combination of Near Infrared (NIR) and red (R) bands generally conditioned by the presence of chlorophyll. The NDVI index has values between -1 and +1, and is used to calculate the health of the vegetation, as well as the density of the vegetation. Values between 0 and 1 mean that the vegetation is healthier, and the higher the value, the better the state of the vegetation (Analytics, E. D. 2023). Values below zero mean that they are non-vegetated areas. This allows the identification of vegetation cover changes and deforestation, droughts, among others, values of 0.2 can be considered to differentiate vegetation from other cover types (Spadoni, et al, 2020).

In the context of NDWI, the interpretation of its values facilitates the identification of geographical features. Low values indicate the presence of water, while higher values indicate terrestrial areas, allowing the identification of water streams and watershed monitoring. This index, with a range of -1 to +1, specializes in water detection. Values near -1 clearly indicate the presence of water, while those near zero suggest less water in the pixel, and values greater than zero correspond to urban or terrestrial areas (Analytics, E. D. 2023).

SAVI values are in the range between -1.5 and 1.5, and from -1.5 to 0 there is presence of water (Sanchez, et al, 2000). NDVI, vital in remote sensing, stands out for its simplicity and adaptability to different sensors, being popular in agricultural monitoring and environmental studies. It is essential to address atmospheric effects, saturation and sensory differences to ensure its effectiveness (Huang, S., et al, 2021).

Remote sensing data play a crucial role in monitoring and mapping vegetation cover, with several Vegetation Indices designed for this purpose. Although NDVI is widely used, it has limitations in areas with moderate and low vegetation densities. The SAVI, which combines indices based on slopes and distances, is considered an optimized alternative. In a study in Anantapur district, a semi-arid region, NDVI and SAVI were compared in 200 samples with various land covers using Landsat imagery. The results suggest that SAVI, with ground factors of 0.5 and 0.9, is more suitable in semi-arid areas, with 0.5 being optimal for vegetation and 0.9 for soils with higher influence (Vani, V. 2017).

Multi-criteria analysis was applied on a GIS platform, considering eight criteria and validating the results with field performance data. The findings indicated that 43% of the land was highly suitable, 41% moderately suitable and 10% marginally suitable. Incorporating fuzzy analysis, 48% were identified as highly suitable, 39% as moderately suitable and 7% as marginally suitable. Performance estimation using vegetation indices showed robust predictive ability, highlighting a combined model with the highest accuracy (R2 = 0.839). This approach underlines the effectiveness of remote sensing on GIS platforms for the selection of arable land areas with improved agricultural potential (Binte R. 2021).

The comparison of the NDVI, NDWI and SAVI indices allows to analyze the existing vegetation and the amount of immersed water. In this way, information of the existing environment is obtained.

Vegetation Sensitivity:

- NDVI: highly sensitive to vegetation density and health.
- NDWI: sensitive to the presence of water and vegetation.
- SAVI: sensitive to vegetation, with an adjustment to reduce the influence of the soil.

Water Identification:

- NDVI: not specific for water detection.
- NDWI: specific for water detection.
- SAVI: not specific for water detection, but can indicate the presence of water at low values.

Sensitivity to water stress:

- NDVI: highly sensitive to water stress.
- NDWI: may indicate areas with water stress, especially when there is a decrease in vegetation values.
- SAVI: less sensitive to water stress compared to NDVI, due to the adjustment term.

Soil Effect Compensation:

- NDVI: sensitive to soil reflectance.
- NDWI: less affected by soil, as it is designed for water detection.
- SAVI: adjustment to reduce the influence of soil, making it less sensitive to soil.

Specific Applications:

- NDVI: widely used in vegetation health assessment.
- NDWI: ideal for detection of water bodies and changes in aquatic cover.
- SAVI: useful when seeking to reduce the influence of soil on the vegetation measurement.

Parameter Setting:

- NDVI and NDWI: no additional adjustments are required.
- SAVI: allows parameter (LL) adjustments to suit different soil conditions.

Temporal Considerations:

- NDVI and NDWI: usually used for seasonal analysis and temporal comparisons.
- SAVI: can be useful in changing soil and vegetation conditions over time.

Multispectral analysis:

- Combining these indices in a multispectral analysis can provide a more complete picture of ecosystem health and environmental conditions.

MATERIALS AND METHODS

This study used the Copernicus platform, from the Sentinel 2 satellite, for which an account was created on the platform. Then the option *explore data*, *copernicus browser*, was chosen and the area of Quito-Ecuador, Guangüiltagua metropolitan park was set. The date of the image and the maximum cloudiness percentage of 20% were chosen, as well as the catalogs where the bands for the analysis (NDVI, NDWI, or SAVI) are found.

Once the images were obtained, radiometric and geometric corrections were made. Also the atmospheric correction, in this case, with the SNAP software, where the images were loaded and proceeded with the synchronization at a resolution of 10 m with which Sentinel 2 operates. Once all the bands were synchronized at this resolution, we entered Raster, and in the *Band Math* option, we could include the index formulas:

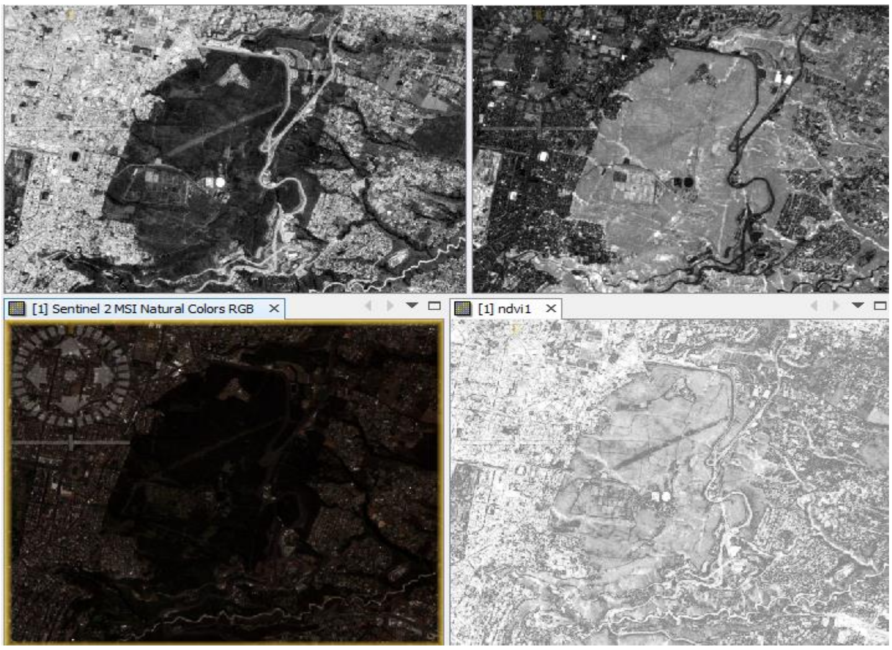
NDVI: (NIR - Network) / (NIR + Network) (eq. 1)
SAVI: ((NIR - Network) / (NIR + Network + L)) x (1 + L) (eq. 2)
NDWI: (NIR - SWIR) / (NIR + SWIR) (eq. 3)

Where
NIR: Band 8
Network: Band 4
L: 0.5
SWIR: Band

RESULTS AND DISCUSSION

The following images were obtained from the process:

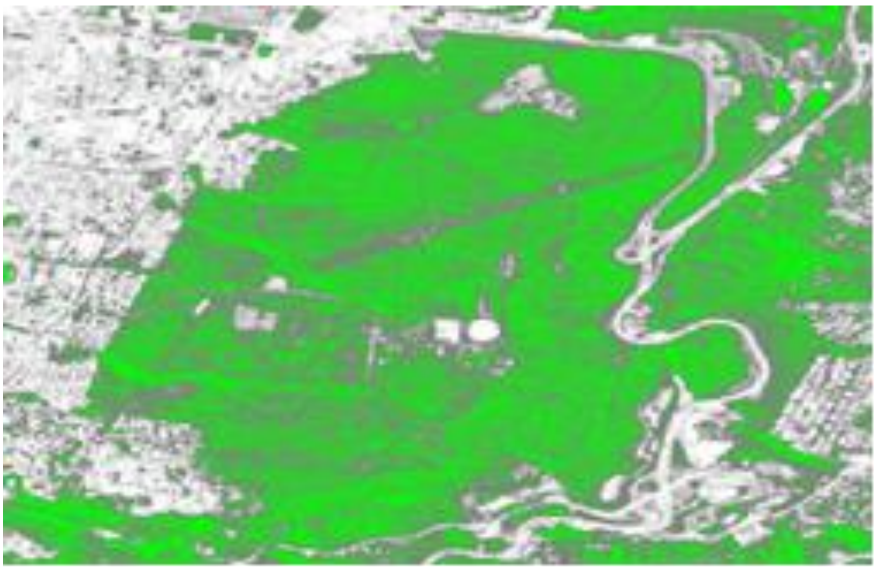
Figure 1. NDVI, SAVI, NDWI, natural colors



Source: Own elaboration with the research data (2023)

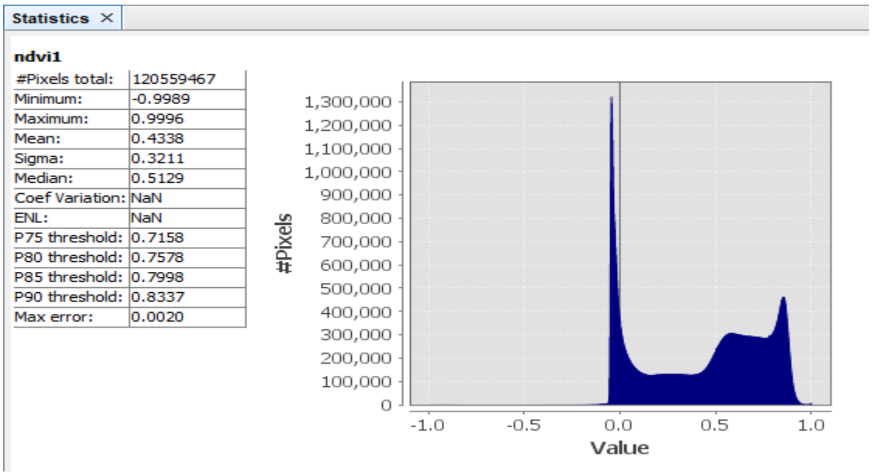
In order to analyze the images generated, some criteria were considered to establish coincidences and non-coincidences between the different images. The NDVI range in the studied area fluctuates between -0.9989 and 0.9996, as shown in Figures 2, 3 and 4. This shows that the analyzed forest area has a high vegetation cover, with very few places without plants. The mean NDVI is 0.4338.

Figure 2. NDVI of Quito's Metropolitan Park



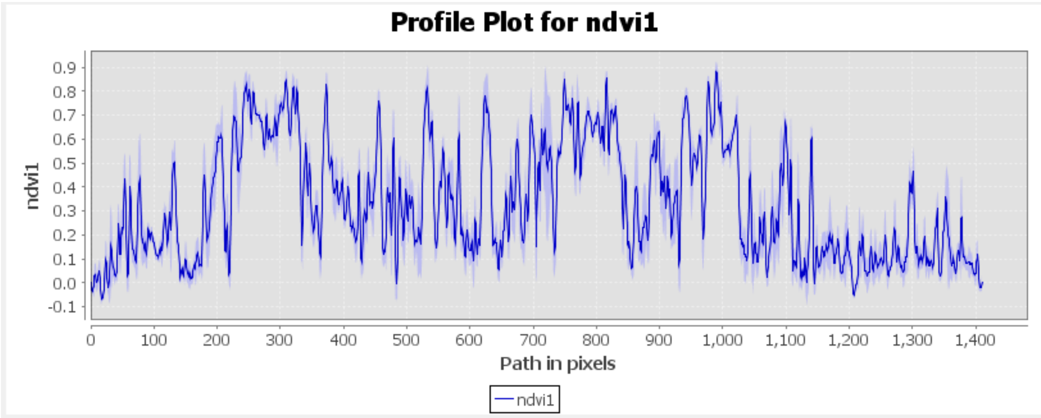
Source: Own elaboration with the research data (2023)

Figure 3. Statistical values of NDVI in Metropolitan Park



Source: Own elaboration with the research data (2023)

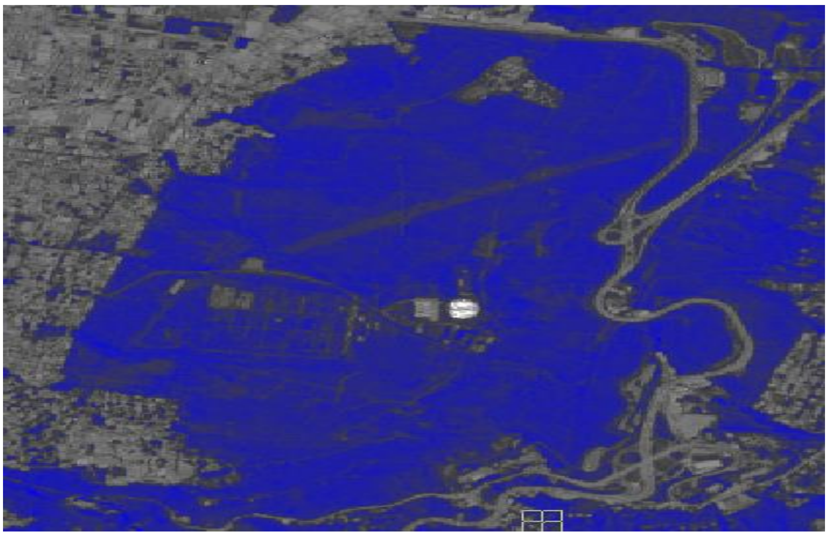
Figure 4. Number of pixels vs NDVI values



Source: Own elaboration with the research data (2023)

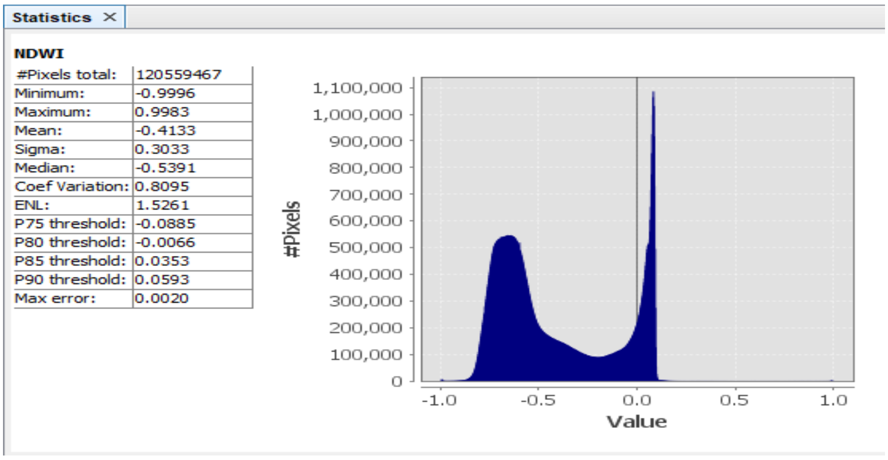
In the case of NDWI, its lowest value is -0.9996, and its highest value is 0.9983, its mean value is -0.4133. The positive values of NDWI correspond to the presence of water. Figure 5 shows in blue the region with the presence of water, which corresponds to the NDVI graph, where there is also vegetation, the average value of NDWI is -0.4133, this refers in general to the presence of water scarcity in the region, which is shown in Figures 6 and 7.

Figure 5. NDWI of the Quito Metropolitan Park



Source: Own elaboration with the research data (2023)

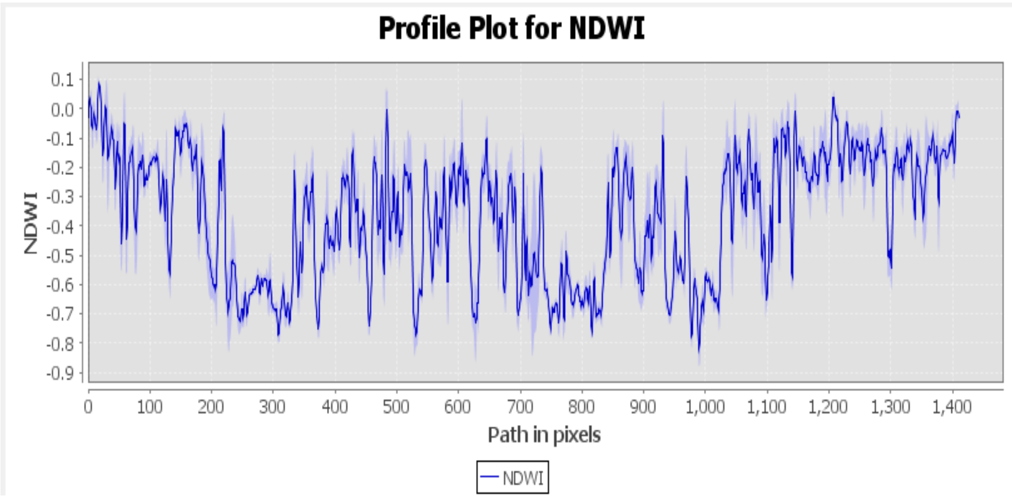
Figure 6. Descriptive statistics of the NDWI values of the metropolitan park



NDWI	
#Pixels total:	120559467
Minimum:	-0.9996
Maximum:	0.9983
Mean:	-0.4133
Sigma:	0.3033
Median:	-0.5391
Coef Variation:	0.8095
ENL:	1.5261
P75 threshold:	-0.0885
P80 threshold:	-0.0066
P85 threshold:	0.0353
P90 threshold:	0.0593
Max error:	0.0020

Source: Own elaboration with the research data (2023)

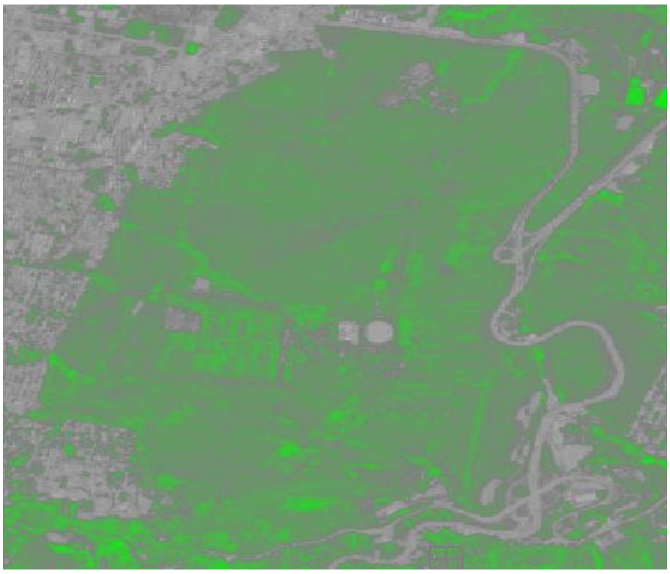
Figure 7. Number of pixels vs. NDWI values



Source: Own elaboration with the research data (2023)

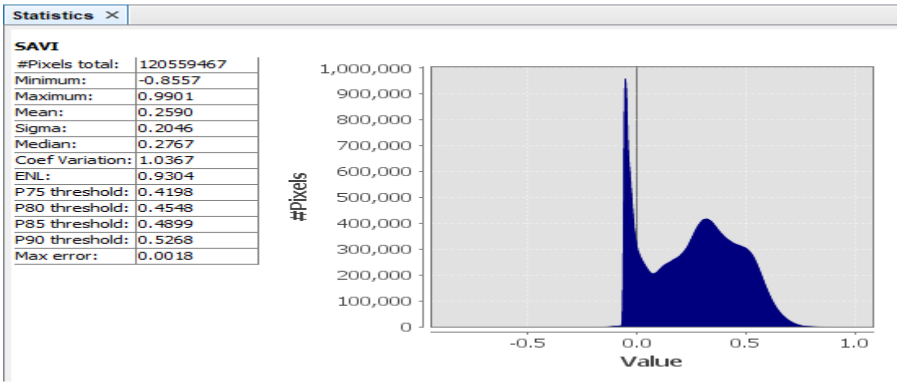
When applying the SAVI formula to the selected area, it is observed that the values oscillate between -0.8557 and 0.9901. This means that there are places where there is a lot of vegetation at ground level, which intersects with tree vegetation, mainly within the forest. In addition, there are places where vegetation is scarce. In the image, the color green is considered for vegetation, and the color lead for places with little vegetation. The SAVI values are according to the Gaussian bell, between 0 and 0.5 at its highest frequency, and the mean is 0.25.

Figure 8. SAVI of the metropolitan park



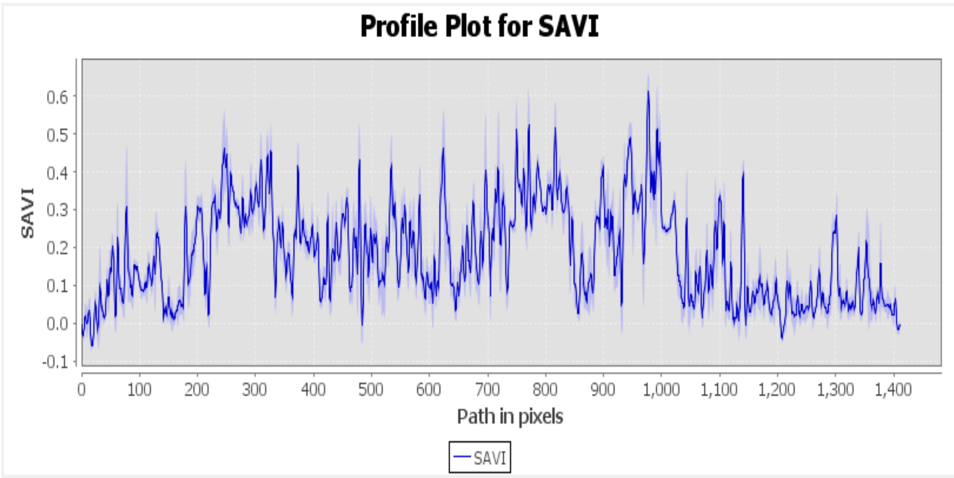
Source: Own elaboration with the research data (2023)

Figure 9. SAVI statistics for Quito Metropolitan Park.



Source**:** Own elaboration with the research data (2023)

Figure 10. Number of pixels vs. SAVI values

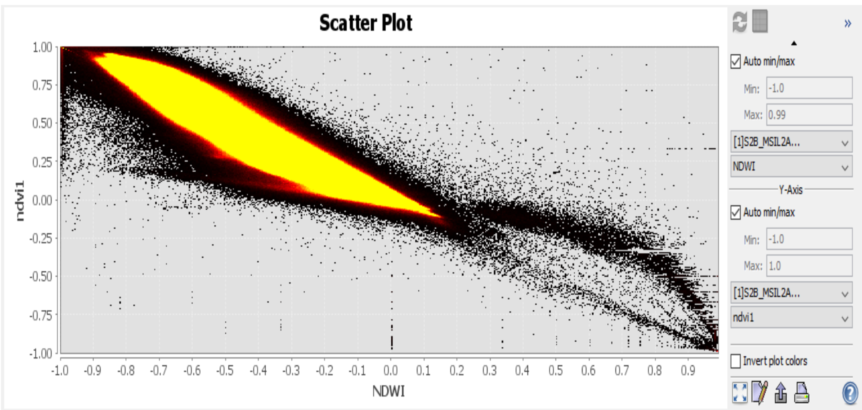


Source**:** Own elaboration with the research data (2023)

Comparative analysis between the indices, NDVI; NDWI SAVI

Comparing these indices gives a clearer picture of what is happening in different environments on the land. If we compare NDVI and NDWI together we can conclude that there are regions where the vegetation is in contact with water, so, around it, there could be a change of vegetation. The image shows the relationship between NDVI and NDWI, which is the region with a yellow color, where in the middle point we can see that the figure becomes wider, which allows us to establish that the existing vegetation is healthy and that it contains little water among its structure. this we find in the second quadrant of the graph, and as the vegetation decreases, the water decreases.

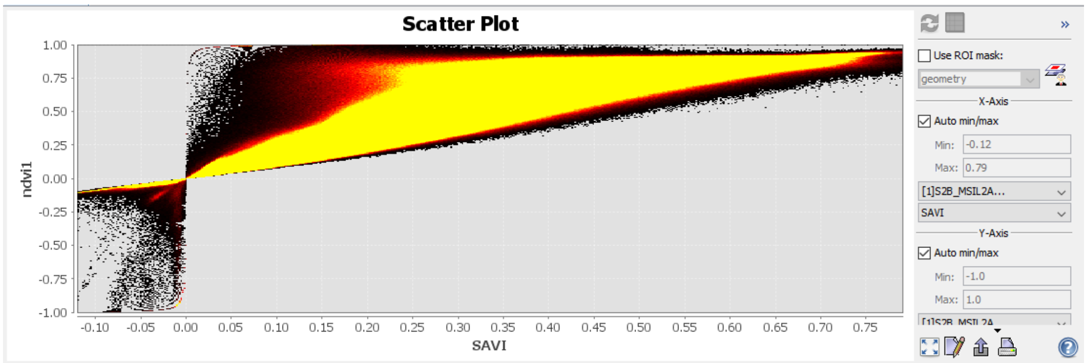
Figure 11. NDVI vs NDWI



Source**:** Own elaboration with the research data (2023)

When comparing the NDVI and SAVI bands, it is observed that the amount of vegetation is dense and very healthy, so NDVI and SAVI values are high. If the NDVI is low and the SAVI is higher, it is deduced that there is water stress, i.e., the amount of water is not enough to satisfy the amount of existing vegetation.

Figure 12. NDVI vs SAVI

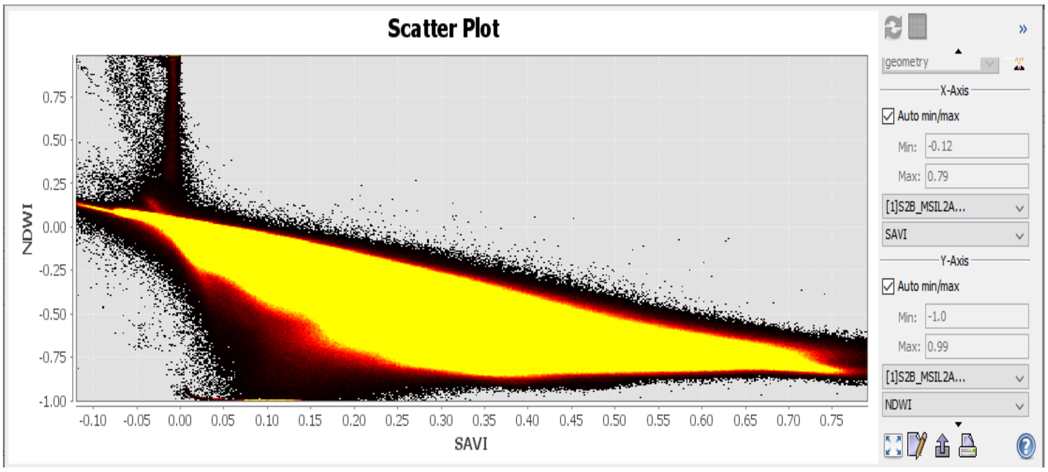


Source**:** Own elaboration with the research data (2023)

The comparison between SAVI and NDWI can be used to estimate the amount of existing water and the health of the vegetation, in Figure 12 we can establish that there is a large amount of water, in addition the positive values of SAVI allow us to establish the existence of dense vegetation, as in the image, in the fourth quadrant.

When the NDWI values are greater than zero, there is the presence of water, but if the SAVI is greater than zero, there is the presence of vegetation, in this case this occurs in a small percentage of the analyzed region, first quadrant. If the NDWI is positive and the SAVI is negative, we are in the case of low vegetation and good humidity, second quadrant. In the third quadrant where NDWI and SAVI are negative, there is practically a shortage of both water and vegetation, as shown in the image below.

Figure 13. NDWI vs SAVI



Source**:** Own elaboration with the research data (2023)

Table 1. Parameters for comparison between indexes

Comparison Parameter	NDVI	NDWI	SAVI
Vegetation Sensitivity	High (0.2 - 0.8)	Moderate (-0.2 - 0.5)	High (0.2 - 0.8)
Water Identification	Non-specific (-1 to 1)	Specific (<0)	Non-specific (low in values) (<0)
Sensitivity to Water Stress	High (<0.3)	Moderate (<0.5)	Less sensitive (>0.1)
Soil Effect Compensation	Sensible	Less sensitive	Adjustment to reduce sensitivity
Common Applications	Vegetation health	Water detection	Soil-adapted vegetation
Parameter Setting	No	No	Yes (parameter LL)
Temporal Considerations	Yes	Yes	Yes

Source: Own elaboration with the research data (2023)

Google Earth Engine (GEE) application, to process the images at a massive scale of Petabytes and by using indices such as NDVI, NDWI, SAVI, in order to evaluate over time the environmental and agricultural impact of the region. The increase in NDVI is usually related to an increase in vegetation water demand (Alvarado, C 2019).

In the study conducted we can indicate that, among the eucalyptus trees, there are spaces that allow light to penetrate these areas, and that the shrub vegetation has developed vertiginously, so the SAVI in certain areas is positive. Which is corroborated with research conducted by (Pacheco et al. 2018).

The Normalized Difference Vegetation Index (NDVI) was applied to identify and evaluate deforestation in the Reserva Natural de la Tierra. This index, which fluctuates between -0.3 and 0.9, is within the accepted limits ranging from -1 to 1 (Campaña, J.et al 2021). This study corroborates the information obtained in the project under study with respect to the ranges obtained from the NDVI.

CONCLUSIONS AND FINAL REMARKS

In the present investigation of the NDVI, SAVI and NDWI spectral indices in the *Guangüiltagua* Metropolitan Park of Quito, a marked presence of vegetation was observed with NDVI values that varied between -0.9989 and 0.9996. This range indicates a significant diversity of vegetation types in the studied area. On the other hand, NDWI showed mean values of -0.4133, suggesting a possible water scarcity in the region. The positive relationship between NDWI and NDVI highlights the connection between vegetation and water bodies in the area.

The application of the SAVI index highlighted areas with dense vegetation at ground level and in the canopy, evidencing the structural complexity of the park. The comparison of NDVI and SAVI revealed regions of possible water stress, where low values in both indices indicate areas where vegetation may be experiencing water scarcity conditions.

These results have significant implications for environmental and urban management, providing valuable information on the health of the ecosystem in Metropolitan Park. However, it is crucial to consider the limitations of the study, such as the resolution of the satellites used and the need to incorporate meteorological data for a more complete understanding of environmental conditions. In summary, this study provides valuable information for understanding the environmental dynamics of the *Guangüiltagua* Metropolitan Park and suggests directions for future research, contributing to the knowledge of the relationship between vegetation, water and environmental conditions in green urban areas.

It is recommended that this approach be applied in other geographic areas to assess ecosystem health and make interregional comparisons. Moreover, the exploration of other combinations of spectral indices and the inclusion of meteorological data are suggested for a more robust analysis.

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Task	**A1**	**A2**	**A3**	**A4**
A. theoretical and conceptual foundations and problematization:	25%	25%	25%	25%
B. data research and statistical analysis:	25%	25%	25%	25%
C. elaboration of figures and tables:	25%	25%	25%	25%
D. drafting, reviewing and writing of the text:	25%	25%	25%	25%
E. selection of bibliographical references	25%	25%	25%	25%
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