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Spatial and Temporal Water Pattern Change Detection through the Normalized Difference Water Index (NDWI) for Initial Flood Assessment: A Case Study of Kuala Lumpur 1990 and 2021

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ABSTRACT

Surface water pattern changes in terms of quantity and directions is caused by many hydrological hazards such as flooding. Rapid urbanization in Kuala Lumpur has destroyed urban forest trees as the most valuable urban green infrastructure (UGI). Then surface, vegetation changes and land transformation, concrete roads, covered roofs, and climate changes impacts changed the water pattern and hydrological system in Kuala Lumpur. Satellite data used to collect data from 1990 and 2021 to show how significant has been these changes. To demonstrate the spatial and temporal changes of hydrological changes in Kuala Lumpur The Normalized Difference Water Index (NDWI) applied for a 30 years assessment. Remote sensing (RS) and Geographical Information Systems (GIS) have helped us detect dynamic changes on the Earth's surface. The mean NDWI of one year was calculated in this study using Kuala Lumpur NDWI from 1990/01/01 to 1990/12/30. The extracted image is larger than the study area and extends beyond Kuala Lumpur's city limits. This image only detected water bodies on the surface of Kuala Lumpur, which is represented in grey or white, such as lakes, rivers, ponds, or any degree of wetness. Because urban forest covered more than 15% of Kuala Lumpur in 1990, surface water was naturally controlled and saved by forest tree and forest soil. Image data for 2021 was taken from Landsat 8, which uses different bands and the same algorithm to visualize NDWI based on the availability of satellite data. The data was averaged over a one-year period between 2021/01/01 to 2021/12/30; as a result, the NDWI in Kuala Lumpur was depicted using the same algorithm from Landsat 8 with different bands. The researchers discovered that urban surface water bodies have increased over the last 30 years, rising from 0.383635 and -.0593184 in 1990 to 0.593288 and -0.44379 in 2021. This indicates that the NDWI index has increased the most in Kuala Lumpur. As previously stated, rapid changes in land use and land cover in the last 30 years have had a negative impact on Kuala Lumpur's NDWI.

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1. Introduction

Urbanization in tropical cities triggers significant land use and cover changes, including the depletion of urban forest trees. These trees, crucial in tropical ecosystems, notably impact water balance and rainfall distribution through transpiration and evaporation. Research highlights their role in altering hydrological patterns according to Bruijnzeel [1] and Costa *et al.,* [2] and worsening floods [3]. Hydrological sources drive shifts in urban surface water patterns. Transformations in soil, surface, topography, elevation, and climate compound these effects have been proven by Ghalehteimouri *et al.,* [4]. Shifting from green urban infrastructure to impermeable surfaces, dominated by buildings and roads with reduced water absorption, disrupts surface hydrology and patterns. These changes resonate across various hydrological systems in flood-prone tropical cities, altering rainfall distribution, evapotranspiration, surface runoff, and recharge [5,6]. Urban flood models range from simple one-dimensional urban drainage models to complex scenarios factoring in mitigation strategies, forecasting spatial and temporal impacts [7,8]. Urbanization and climate shifts increase flooding risks in tropical cities, driven by factors like surface changes, drainage constraints, and wetland loss. These elements elaborate urban flooding and extreme weather impacts [9].

Urban land use drives dynamic changes, impacting surface moisture and flood susceptibility. Changes in moisture alter exposure, reduce water penetration, and worsen flooding, with soil moisture playing a pivotal role in earlier literature [10,11]. Urbanization accentuates flood risks through increased soil moisture and rainfall intensity [12]. Combining satellite-based remote sensing data, The Normalized Difference Water Index (NDWI) analysis reveals water trends, guiding decision-making and enhancing flood management [13]. Furthermore, NDWI is able to calculate for surface water and potential water in urban areas. With historical ground data often elusive, satellite accuracy underscores the need for calibrated data. Urbanization's role in hydrological changes poses escalating flood risks, necessitating robust water management. Observing Kuala Lumpur's dynamic land use changes over 30 years due to rapid population growth, rapid urbanization negatively affects hydrological processes, altering flooding patterns and frequency due to high land concentration and value [14]. Hazards, defined as dangerous phenomena causing harm, prompt critical assessment techniques. NASA's satellite analysis revealed significant water distribution changes in Kuala Lumpur [15]. Previous studies focused on flood simulation, rainfall-flood correlation, and Monsoon [16,17]. This study aims to show how rapid urbanization in Kuala Lumpur affects flood risk and Urban Green Infrastructures UGI. It uses remote sensing and Geographic Information System GIS to provide insights for sustainable urban development and policy planning.

2. Methodology

2.1 Study Area

The Kuala Lumpur's absolute geographical location is DMS Latitude 3° 8' 27.0708'' N, DMS Longitude 101° 41' 35.5452'' E which introduce a tropical climate with heavy rain. According to the most recent records and assessments, flooding is one of the most frequent hydrometeorological hazards in Kuala Lumpur as shown in Figure 1 [18].

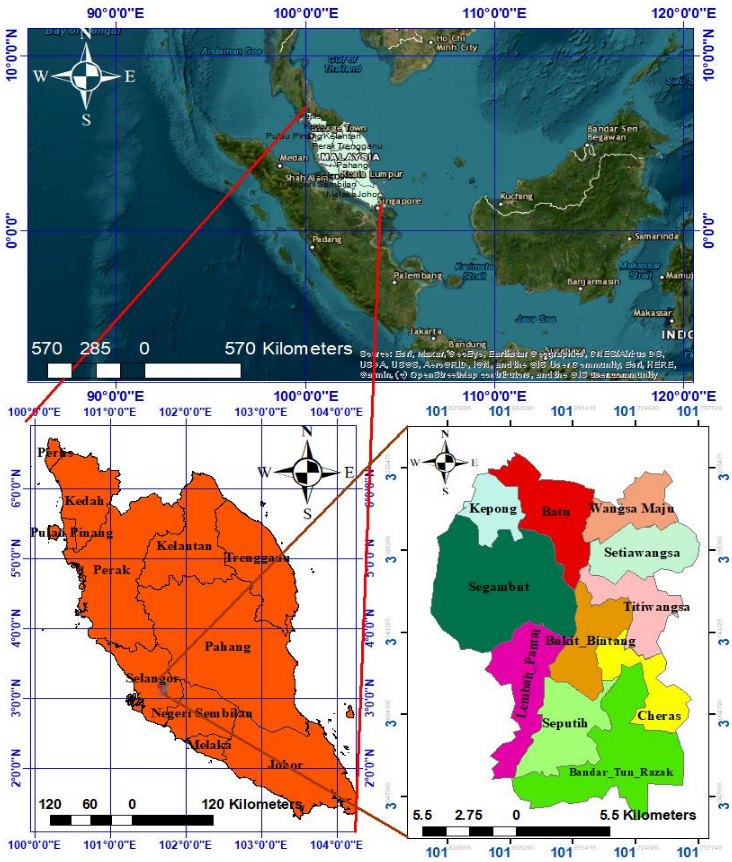

Fig. 1. Study area

2.2 Methods Applied

The NDWI was established in order to improve water-related landscape aspects. This index employs the near infrared (NIR) and short-wave infrared (SWIR) bands. Use the following formula to calculate NDWI:

$$NDWI = (NIR - SWIR) / (NIR + SWIR) \quad (1)$$

For Landsat 5 data,

$$NDWI = (Band\ 4 - Band\ 5) / (Band\ 4 + Band\ 5) \quad (2)$$

For Landsat 8 data,

$$NDWI = (Band\ 5 - Band\ 6) / (Band\ 5 + Band\ 6) \quad (3)$$

Methodological documentation ensures reproducibility and transparency in NDWI estimation. NDWI ranges from -1 to 1, with water bodies having NDWI > 0.5, distinct from lower vegetation values. Techniques like solar and thermal radiation, plus microwave emission, enhance water-covered area visibility in remote sensing images. Reflected solar radiation, achieved by single bands or band ratios, improves open water visibility in photography [19]. NDWI estimation is vital for highlighting open water bodies in remote sensing satellite imagery, rendering them distinct from surroundings. Channels at 0.86 m and 1.24 m on high-reflectance vegetation canopies detect similar depths, while liquid water absorption is minimal at 0.86 micrometers and even less at 1.24 micrometers. Canopy scattering enhances water absorption. Changes in vegetation water content impact NDWI evaluated by Zahari and Ariffin [20]. Therefore, based on the band colors the following formula uses to calculate NDWI:

$$NDWI\ equation: (Green - NIR) / (Green + NIR), \quad (4)$$

3. Results

3.1 The Normalized Difference

3.1.1 The Normalized Difference Water Index 1990

RS and GIS employ emerging remote sensing tech and satellite data for dynamic Earth surface change detection, revolutionizing environmental assessments. NDWI's utility extends across broader scales, streamlined by historical change evaluation. Satellite-based NDWI, reliant on accurate historical data, is crucial for environmental quality assessments. Leveraging Landsat 5's 1990 satellite data, this study connects NDWI with tropical cities, benefiting areas like agriculture, hydrology, climate change, and water balance. The study calculates mean NDWI for a year using 1990 NDWI data from Kuala Lumpur, highlighting surface water prevalence. This image encompasses areas beyond Kuala Lumpur's city limits, revealing water bodies in grey or white. Notably, with over 15% urban forest coverage in 1990, forest trees and soil retained surface water, evident in Figure 2.

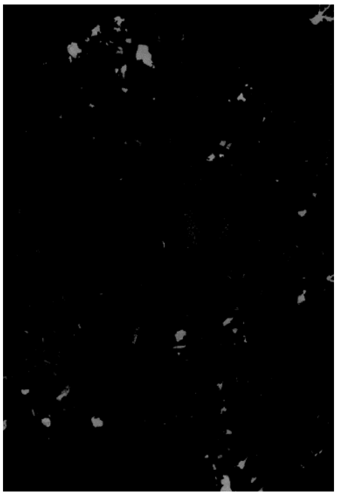

Fig. 2. Kuala Lumpur raw satellite image in 1990

3.1.2 The Normalized Difference Water Index 2021

Over three decades, Kuala Lumpur's satellite imaging and NDWI evolution witnessed substantial changes due to extensive land transformation. Urban growth, driven by diverse land uses, altered NDWI patterns tied to shifts in natural resources and UGIs. Notably, vital tropical urban green assets like urban forest trees declined by over 50% between 1990 and 2021 due to changing land cover. Utilizing Landsat 8's 2021 image data and a consistent algorithm, NDWI visualized evolving hydrology from January 1 to December 31, 2021, depicting Kuala Lumpur's changes. Rapid urbanization in Kuala Lumpur over the last 30 years transformed water dynamics due to land conversion and interactions among various land uses and covers. Satellite images use NDWI values to gauge shifts in water bodies, linked to environmental concerns like flooding and droughts, impacting well-being and ecosystems.

Assessing urbanization, land use, and cover changes helps comprehend origins, impacts, and potential trends of hydro-meteorological hazards, as in Figure 3.

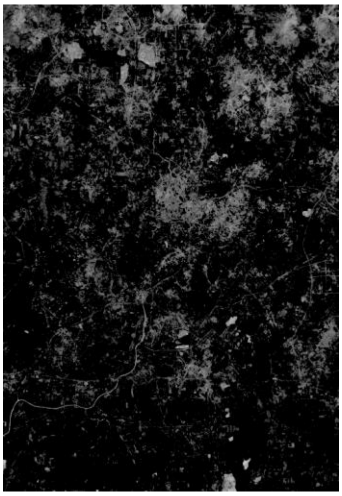

Fig. 3. Kuala Lumpur raw satellite image in 2021

3.1.3 Calibration of Normalized Difference Water Index 1990

Understanding NDWI's resource implications across geographies is vital. The 1990 NDWI range of -0.593184 to 0.383635 aligns with water value expansion, depicted by blue areas signifying high absorption. Dark orange hues represent UGIs and forest land use, highlighting their link. Urban ecosystem regulation hinges on factors like reduced green infrastructure, notably urban forest trees acting as water filters and reservoirs in 1990, aiding flood control in tropical cities. Bukit Bintang's low UGI values in 1990 suggest possible neglect of green spaces and sustainability. Conversely, developed areas display positive NDWI values, likely due to water-intensive practices like irrigation. Districts bordering water bodies, e.g., Batu, Kepong, Seputih, Cheras, and Lembah Pantai, show notably positive NDWI values, emphasizing their water-rich environments. This analysis underscores NDWI's role in urban development and environmental resilience. NDWI is vital for urban natural resource assessment, supporting a balanced ecosystem foundation. Understanding temporal and spatial NDWI variations is crucial for flood risk assessment and urban resilience in rapidly growing Kuala Lumpur. Urban forest tree declines since 1990 led to unprecedented NDWI lows. In this Southeast Asian city, NDWI is pivotal for ecological equilibrium and resilience. Recognizing NDWI's significance and its link with urban resources is vital for sustainable development. Prioritizing green infrastructure and urban forest trees can shape a resilient urban future, as in Figure 5.

3.1.4 Visualization of Normalized Difference Water Index 1990

NDWI's geographic range provides crucial insights. In 1990, NDWI spanned 0.383635 to -0.593184, reflecting water presence as shown in Figure 4 in black and white. Furthermore, visualized in Figure 5 and blue represents absorption, dark orange symbolizes UGIs and forests. This shows UGI-water body links, vital for urban ecology. Urban forests stored water in 1990, key for floods. Lower Bukit Bintang UGI values suggest green space neglect. Developed areas had positive NDWI due to water use, water-adjacent zones had notably high NDWI. This underscores NDWI's role in urban dynamics, development, green spaces, and water management. It assesses urban resources and balances ecology. Understanding NDWI variations amid Kuala Lumpur's growth is vital for flood risk and resilience. Urban forests led to low NDWI in year 1990. Recognizing UGI significance and urban forests, Kuala Lumpur can ensure a resilient, sustainable future.

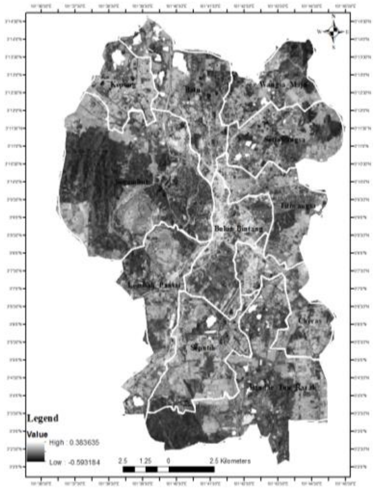

Fig. 4. Kuala Lumpur NDWI value in 1990

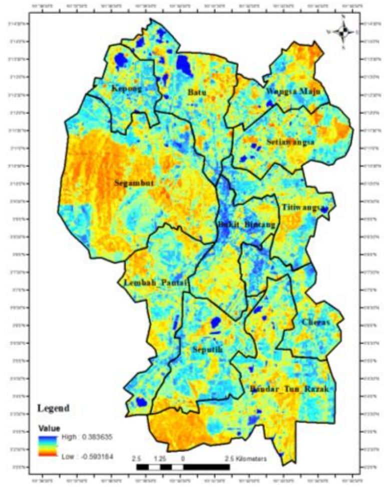

Fig. 5. NDWI and UGIs 1990

3.1.5 Calibration of Normalized Difference Water Index 2021

Kuala Lumpur's UGI naturally filters urban water, vital for its tropical urban ecosystem and water cycle, enhancing quality and impacting urban ecology. Through NDWI analysis utilizing Landsat 8 data, water body changes in year 2021 can be observed. Urban surface water bodies expanded over 30 years, from 1990's 0.383635 and -0.0593184 to 2021's 0.593288 and -0.44379, highlighting significant NDWI index rise due to rapid land changes. In contrast, Kuala Lumpur has witnessed a significant reduction in the NDVI values 0.593164 to -383635 in 1990 while in 2021 significant decline, 0.80032774 to -0.539414.

The key UGI components, urban forest tree has reshaped Kuala Lumpur's NDWI pattern from 1990 to 2021, with increases noted in many areas, including Bukit Bintang and district edges, and Wangsa Maju. These shifts reflect urbanization and industrialization's impact, bringing progress and challenges. Sustaining UGIs, especially in rapidly evolving zones like Bukit Bintang, is vital for long-term resilience. Despite these challenges, the city's northern region with ponds, lakes, and lagoons maintained a high NDWI index compared to 1990. Overall, Kuala Lumpur's NDWI value rose due to rapid urbanization, evident in Landsat 8's raw spectral image as illustrated in Figure 6.

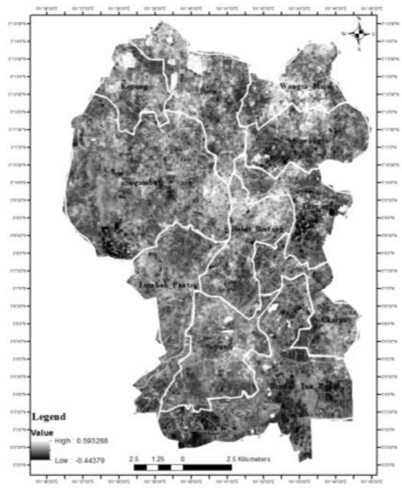

Fig. 6. Kuala Lumpur NDWI value in 2021

3.1.6 Visualization of Normalized Difference Water Index 2021

Rapid urban expansion reshaped Kuala Lumpur's surface through construction, altering flows and creating wetlands. Urban forest clearance transformed the environment, while water body reduction resulted from redevelopment and new settlements, particularly in the south. Urbanization and flood risks intensify heat, impacting temperature. Satellite images reveal significant NDWI changes in UGI and urban development. Construction areas and urban transformation show higher NDWI values than in 1990. Rapid urbanization and land use changes challenge planning. Kuala Lumpur lacks precise hydro-meteorological considerations. Remote sensing and GIS optimize UGI management for coexistence. High NDWI values in Bandar Tun Razak, Segambut, and Titiwangsa signify established UGIs. Conversely, lowlands exhibit high NDWI values, possibly due to irrigation. Analyzing NDWI in cities like Kuala Lumpur is vital, highlighting UGIs' importance and conservation efforts, as illustrated in Figure 7.

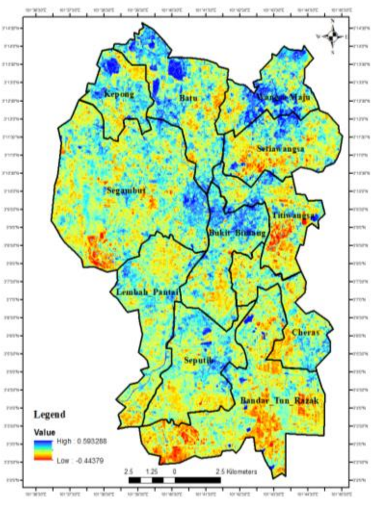

Fig. 7. NDWI and UGIs 2021

3.2 Effectiveness of Urban NDWI Studies in Kuala Lumpur

For a comprehensive assessment of Kuala Lumpur's present and future resilience, multiple aspects of urban ecosystem services, including UGIs and water values, require scrutiny. Utilizing historical high-resolution satellite data is crucial for this approach. Such data unveils causes of flooding, including altered river concentrations and UGI. Evaluating the impact of land use and cover changes on urban floods, along with drainage patterns and hydrological systems, is vital. The 1990 satellite image analysis underscores forest trees' role in water absorption and storage, evident through NDWI. Notably, districts like Batu, Kepong, and Bukit Bintang feature prominent water bodies, with forest trees excelling in water absorption. Developed areas exhibit minor NDWI changes, potentially affecting green spaces' water-absorbing capacity due to urbanization. The urban NDWI index assesses UGI significance. Leveraging GIS software enhances precise analysis of transformations and their causes amid land use and cover changes.

Spatial and temporal NDWI changes in Kuala Lumpur are influenced by natural and climatic factors, alongside other variables. Urban growth alters topography and geomorphology, impacting NDWI. Land use influences stormwater velocity, soil degradation, and sedimentation. Urban settlements disrupt watershed function, impacting hydrology. Development significantly affects NDWI, with urban forest-rich areas showing lower water values. This highlights green space preservation for resilience Figure 8. Studies highlight UGI benefits and land use change detection. Surface hydrology networks and NDWI receive less attention despite diversity. Satellites aid hydrological risk analysis and water quality monitoring. NDWI and green infrastructure need focus in urban and tropical settings. 2021 development reduces NDWI via urban forest loss, affecting water control. Urban forests regulate runoff through canopy interception. NDWI and LULC analysis highlight urban forest trees' water role. Declining forests alter hydrology. Recognizing UGI importance, especially urban forest trees, is vital for water management and resilience Figure 9.

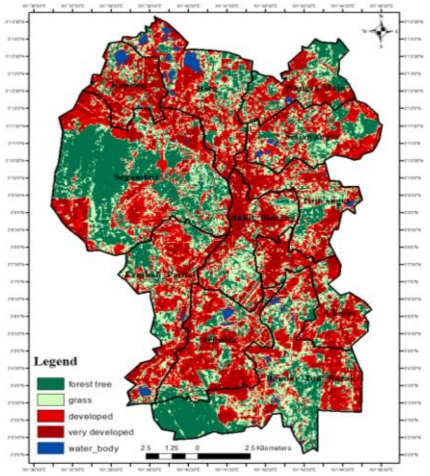

Fig. 8. Urban NDWI and urban development in 1990

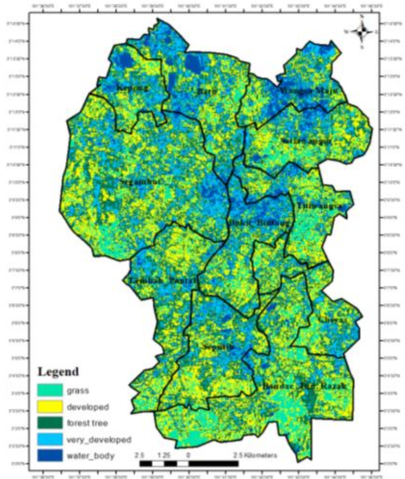

Fig. 9. Urban NDWI and urban development in 2021

The 2021 NDWI and LULC analysis shows shifts in urban forest trees' water absorption. Urban forest destruction raised NDWI citywide, but their water-absorbing capacity decreased since 1990. Grasslands and developed areas excel in retention. Despite NDWI's utility, surface hydrological features are overlooked. Satellite-based water detection aids hydrological risk assessment and quality monitoring. NDWI and green infrastructure importance is underestimated, especially in tropical settings. By 2021, development halved urban forest trees' water control, reducing regulation.

Urban forests, rainfall interceptors and reservoirs, play vital roles. Kuala Lumpur faces challenges in urban planning, land use, and environment. Past urbanization and emerging issues integrate with climate projections. Careful land selection prioritizes resilience, mitigation, and sustainability.

4. Conclusions

Since 1990, rapid urbanization and industrialization have stimulated dynamic land use changes in Kuala Lumpur. The NASA Landsat time series based on different band selection satellites made it possible to visualize the water values. Therefore, in this study NDWI values based on defined bands in the Landsat 5 and 8 have been selected for the last 30 years. Therefore, NDWI growth from 1990's 0.383635 to 2021's 0.593288 highlights increased surface water bodies. This transformation intensified hydrological patterns with significant urban forest reduction, escalating flood hazards due to limited hydrologic budget and reduced water penetration. This study showed that urban forest trees are essential for the ecosystem services and their reduction associate with urban water patterns changes and urban flood risks.

Understanding local and regional urban land use changes and their link to floods is crucial for Kuala Lumpur's flood assessment. Previous policies should incorporate geographical and biological factors. Integrating hydrological elements and floods is vital for effective hazard adaptation. As Kuala Lumpur develops, sustainable planning and environmental understanding are key. Balancing growth with UGI preservation, especially urban forests, aids resilience. Holistic approaches by policymakers and planners are vital for Kuala Lumpur's sustainable future.

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