Is Indonesia's New Capital at Risk of Urban Heat Stress?: A Perspective

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Abstract

Rapid urban development modifies land surface properties, atmospheric composition, and hydroclimatic processes, which has resulted in with important implications for urban heat stress, climate resilience, and public health, particularly in tropical regions. This perspective examines whether Ibu Kota Nusantara (IKN) is entering an early phase of heat-prone urban transformation by integrating satellite-derived land surface, atmospheric, and rainfall indicators within a cloud-based environmental computing framework. The temporal trends in the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Land Surface Temperature (LST), carbon monoxide (CO), nitrogen dioxide (NO_2), methane (CH_4), and annual rainfall for 2013–2023 period were obtained from Google Earth Engine. The results reveal distinct vegetation decline, rapid built-up expansion, and a substantial rise in surface temperature following the acceleration of large-scale development after 2022. Concurrent increases in CO, NO_2, and CH_4 were observed, while rainfall variability alone did not explain the vegetation loss. These signals have indicated an emerging risk of urban heat stress and highlight the value of satellite-based environmental computing for early-warning detection and climate-sensitive urban planning.

1. Introduction

Urban land cover transformation is a fundamental driver of changes in local thermal environments, primarily through the replacement of vegetated surfaces with watertight structures that absorb and retain heat [1,2]. In tropical climates, where high humidity and elevated baseline temperatures already constrain human thermoregulation, such transformations substantially magnify heat exposure that lead to public health risks [3,4]. These challenges are further intensified by global warming, which increases the frequency and severity of extreme heat events and places growing pressure on rapidly urbanizing cities.

Indonesia's New Capital (IKN Nusantara) represents one of the most ambitious urban development initiatives in Southeast Asia, with large-scale physical construction accelerated since 2022 as part of a national vision for a smart, sustainable, and climate-resilient city **[5]**. As a planned city developed largely from scratch, IKN offers a unique opportunity to integrate climate adaptation, mitigation, and digital innovation from the earliest stages of urban growth. Within this context, satellite-based indicators, such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Land Surface Temperature (LST) provide robust spatial and temporal metrics to monitor land cover dynamics and their thermal consequences in near real time **[6,7]**.

Beyond land surface transformation, early urbanization also modifies atmospheric composition and interacts with hydroclimatic variability, both of which directly influence surface energy balance and human heat exposure. Combustion-related pollutants, such as carbon monoxide (CO) and nitrogen dioxide (NO_2), provide early signals of construction activity, transportation, and energy use, while methane (CH_4) represents a key greenhouse gas associated with land disturbance and infrastructure development.(11-13).

In addition, concurrent increases in CO, NO_2, and CH_4 concentrations suggest intensifying anthropogenic activity during the early phase of urban development, consistent with satellite-based atmospheric observations in rapidly urbanizing regions **[8–10]**. At the same time, rainfall variability plays a fundamental role in regulating vegetation dynamics in tropical environments and must be considered to distinguish climate-driven fluctuations from anthropogenic land cover change (14). The integration of satellite-derived land surface indicators with atmospheric composition and rainfall through cloud-based environmental computing provides a comprehensive framework for detecting early land–atmosphere responses and emerging urban heat stress in Indonesia's New Capital under ongoing global warming **[11]**.

2. Study Area and Data Sources

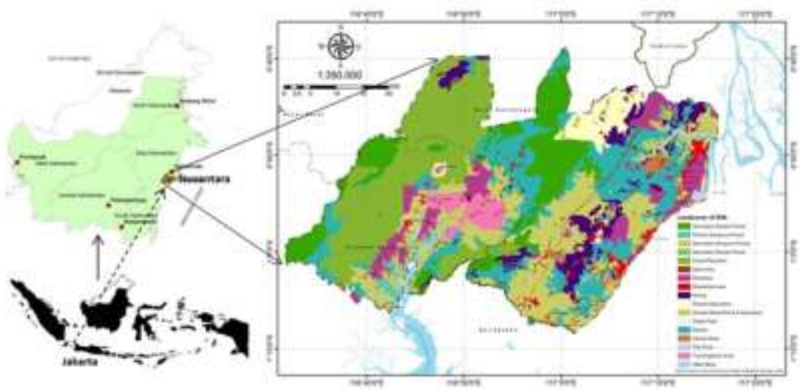

Figure 1. Location of Indonesia's New Capital (Ibu Kota Nusantara, IKN) in East Kalimantan, Indonesia, encompassing parts of Penajam Paser Utara and Kutai Kartanegara regencies [15].

The study area is Indonesia's New Capital, Ibu Kota Nusantara (IKN), located in East Kalimantan Province on the island of Borneo (Figure 1), which is approximately bounded by 116.6°–117.3° East longitude and 1.5°–0.7° South latitude, corresponding to the analysis extent used in Google Earth Engine. The IKN planning area encompasses parts of Penajam Paser Utara and Kutai Kartanegara regencies and lies within a tropical humid climate zone characterized by high annual rainfall, dense natural vegetation, and relatively stable thermal conditions prior to large-scale development. Since the formal designation of IKN and the acceleration of construction activities beginning in 2022, the region has undergone rapid land clearing and infrastructure expansion, making it a critical case for examining early-stage land–atmosphere interactions and emerging urban heat stress.

All spatial analyses were conducted using cloud-based environmental computing within Google Earth Engine (GEE) [10]. NDVI, NDBI, and LST were derived from Landsat 8 and Landsat 9 imagery. Atmospheric indicators (CO, NO_2, CH_4) were obtained from Sentinel-5P TROPOMI products, while rainfall data were sourced from the CHIRPS precipitation dataset [14]. All datasets were spatially aggregated over the IKN boundary and summarized into annual values to ensure comparability.

3. Computational Analysis of Land Surface, Atmospheric, and Hydroclimatic Indicators

This section integrates land surface, atmospheric, and hydroclimatic indicators within a cloud-based computational framework to identify early environmental signals associated with urban development in Indonesia's New Capital. All indicators were derived from satellite observations and processed using Google Earth Engine, enabling consistent spatial averaging and temporal comparison across datasets with different resolutions and physical units [11].

By integrating multiple satellite-derived indicators within a unified computational environment, this analysis captures coupled land–atmosphere responses that are often missed when variables are examined independently. Such integration is particularly important in rapidly developing tropical regions, where land surface transformation, atmospheric emissions, and climate variability interact nonlinearly to shape surface thermal conditions. The computational approach adopted here enables early detection of synchronized changes across indicators, providing an effective early-warning framework for emerging urban heat stress [1,2].

3.1 Land Surface Indicators

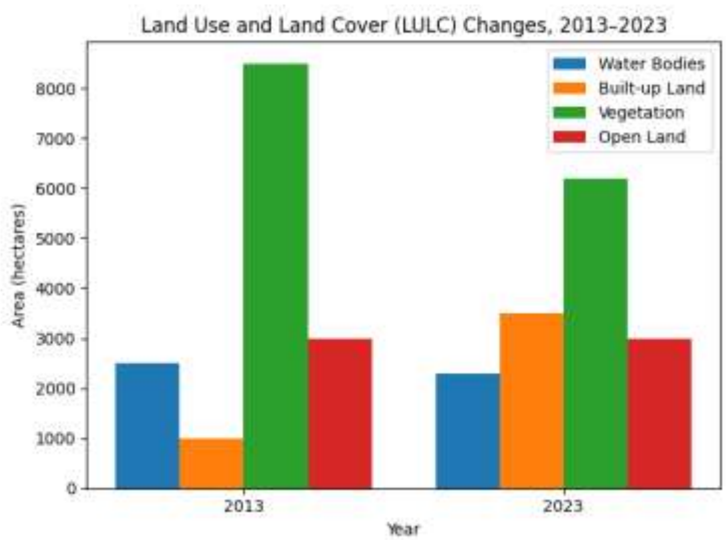

Figure 2. Land use and land cover (LULC) changes in IKN between 2013 and 2023.

Figure 2 illustrates land use and land cover (LULC) changes in IKN between 2013 and 2023, revealing substantial landscape transformation over the last decade. Vegetated areas decline markedly, while built-up land expands significantly, reflecting accelerated urban development and infrastructure construction during the early establishment of Indonesia's new capital. The reduction in vegetation cover implies diminished evapotranspiration capacity and surface cooling potential, whereas the expansion of impervious surfaces enhances heat storage and alters surface energy balance. Similar LULC transitions have been widely identified as primary drivers of surface warming and urban heat island development, particularly in rapidly urbanizing tropical regions (Oke, 1982; Weng et al., 2004; Li et al., 2017). Vegetation dynamics were quantified using the Normalized Difference Vegetation Index **(NDVI)**, calculated as:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where **NIR** represents near-infrared surface reflectance and **RED** represents red-band surface reflectance. NDVI values range from −1 to +1, with higher values indicating denser and healthier vegetation. NDVI serves as a robust proxy for vegetation cover, photosynthetic activity, and evapotranspiration capacity, all of which play a critical role in regulating surface energy balance and surface cooling in urban and peri-urban environments [1,2].

Urban surface expansion was assessed using the **Normalized Difference Built-up Index (NDBI)**, expressed as:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$$

where **SWIR** denotes shortwave infrared reflectance and **NIR** denotes near-infrared reflectance. Higher NDBI values indicate a greater dominance of impervious built-up surfaces such as concrete and asphalt. Numerous studies have demonstrated a strong positive relationship between increasing NDBI and surface warming, reflecting reduced evaporative cooling and enhanced heat storage capacity in urban environments [6,7].

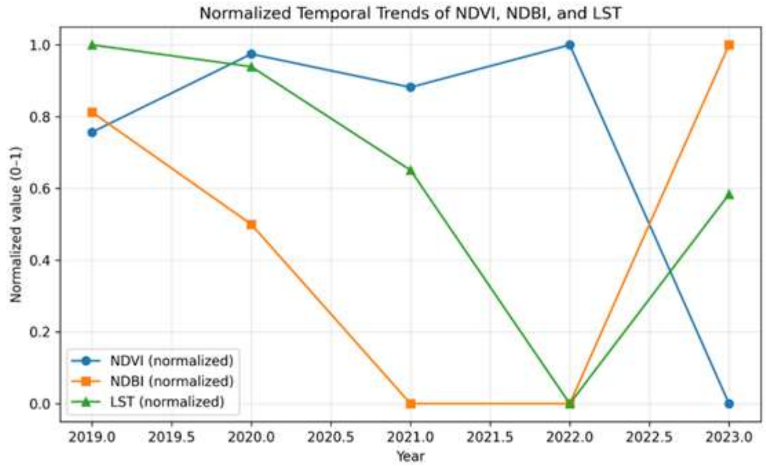

Figure 3. Temporal trends of NDVI, NDBI, and land surface temperature (LST) in IKN during 2013–2023.

Temporal analysis of vegetation greenness (NDVI), built-up intensity (NDBI), and land surface temperature (LST) reveals a sharp NDVI decline after 2022, accompanied by rapid increases in NDBI and normalized LST. These coupled trends indicate surface sealing, vegetation loss, and enhanced heat storage consistent with early-stage urban heat island development [1,2].

3.2 Atmospheric Composition Indicators

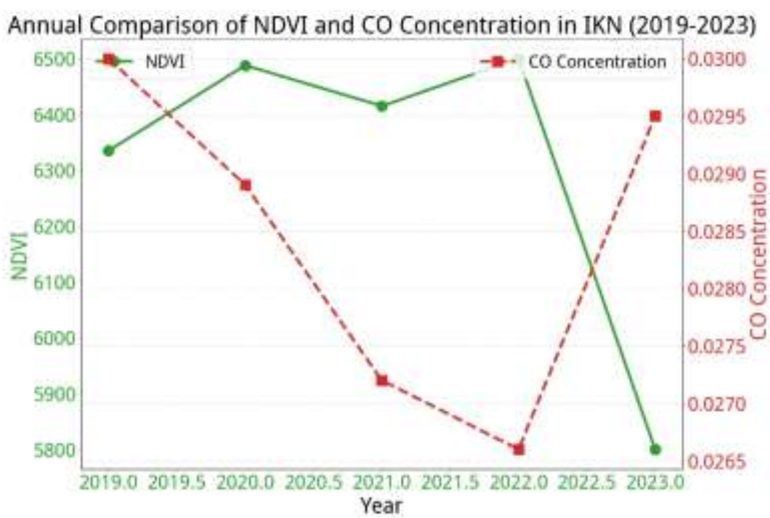

Figure 4. Annual comparison of NDVI and carbon monoxide (CO) concentrations in IKN.

Figure 4 illustrates the annual relationship between vegetation greenness (NDVI) and carbon monoxide (CO) concentrations in IKN. A declining NDVI coincides with increasing CO levels after 2022, suggesting intensifying combustion-related activities associated with early urban development and infrastructure expansion, consistent with satellite-based observations in rapidly urbanizing regions.

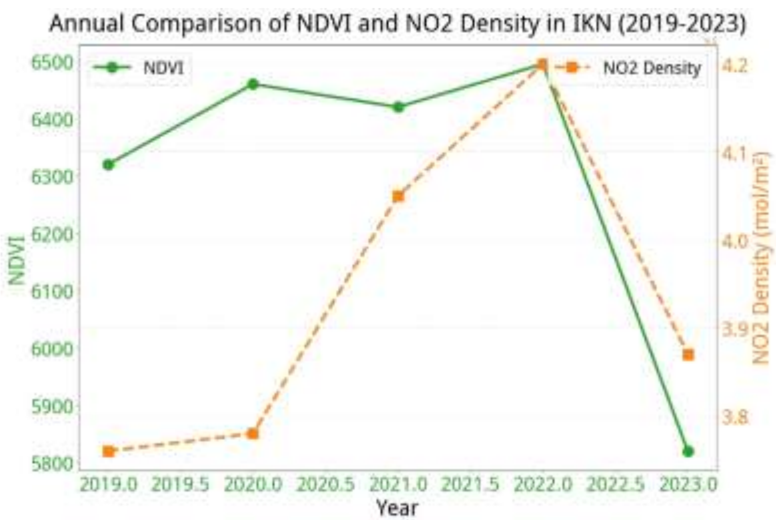

Figure 5. Annual comparison of NDVI and nitrogen dioxide (NO_2) density in IKN.

Figure 5 shows the NDVI–CO relationship, where declining vegetation greenness after 2022 coincides with increasing CO concentrations, suggesting intensifying combustion-related activity. Figure 6 presents the NDVI–NO_2 relationship, indicating elevated anthropogenic emissions linked to construction and transportation activity prior to the pronounced vegetation decline. Figure 7 illustrates the NDVI–CH_4 relationship, where elevated CH_4 concentrations concurrent with NDVI reduction point to land disturbance and greenhouse gas emissions associated with infrastructure development. Although TROPOMI provides column-averaged concentrations, the temporal coherence with land surface change supports their use as early indicators of development-driven environmental stress [7,12].

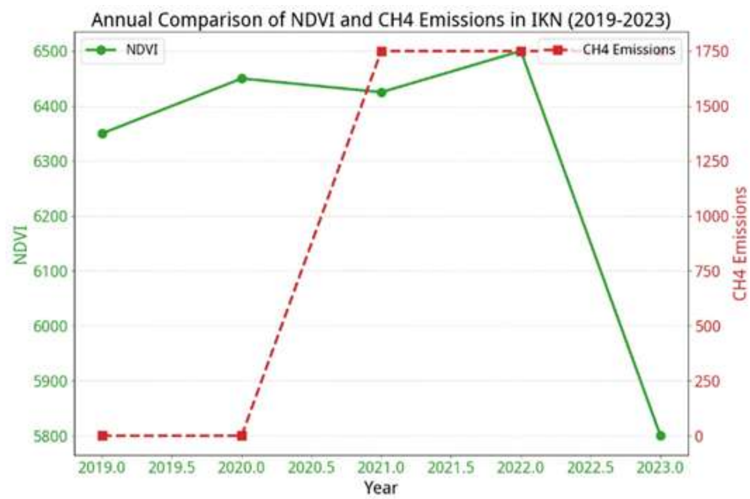

Figure 6. Annual comparison of NDVI and methane (CH_4) concentrations in IKN.

Atmospheric composition indicators were included to capture early emission signals associated with construction activity, transportation, and land disturbance. Carbon monoxide (CO), nitrogen dioxide (NO_2), and methane (CH_4) derived from Sentinel-5P TROPOMI serve as proxies for combustion-related activity and greenhouse gas emissions at the regional scale [8].

Declining NDVI coincides with increasing CO, NO_2, and CH_4 concentrations, suggesting intensifying anthropogenic pressure during early urbanization. Although these products represent column-averaged concentrations, they are well suited for detecting temporal trends in rapidly transforming landscapes [9,10].

3.3 Hydroclimatic Indicator

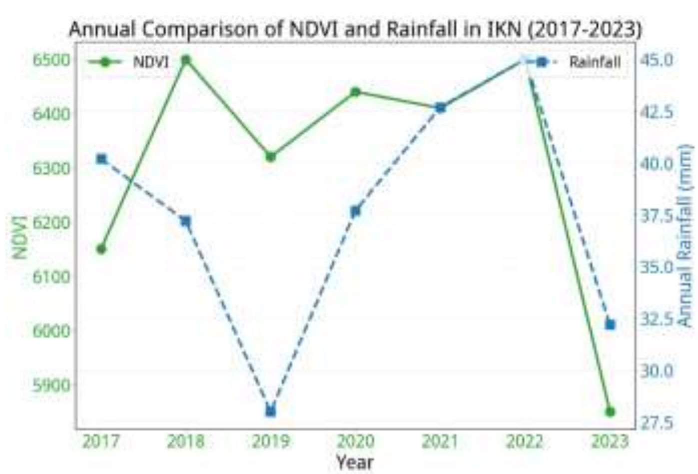

Figure 7. Annual comparison of vegetation greenness (NDVI) and rainfall in IKN.

Annual rainfall was incorporated to represent hydroclimatic forcing and to distinguish climate-driven vegetation variability from anthropogenic land cover change. Rainfall data were derived from the CHIRPS dataset [12]. While NDVI generally follows interannual rainfall variability in earlier years, a clear divergence emerges after 2022, when NDVI declines sharply despite rainfall levels that are not anomalously low. This decoupling indicates that recent vegetation loss is increasingly driven by urban development rather than hydroclimatic variability alone.

Taken together, the concurrent decline in NDVI, increase in NDBI and LST, rising atmospheric pollutant and greenhouse gas concentrations, and the decoupling of vegetation dynamics from rainfall variability provide converging evidence of a development-driven environmental transition in IKN. From a computational perspective, the alignment of these independent indicators strengthens confidence in the observed trends and reduces the likelihood that they are driven by short-term climatic anomalies. These coupled signals suggest that IKN is entering a heat-sensitive urban trajectory, underscoring the value of integrated satellite-based computing for early detection of urban heat stress risk in planned tropical cities [1,8,11].

4. Conclusion

This perspective analyzes whether Indonesia’s New Capital (IKN) is at risk of urban heat stress. The analysis was conducted by integrating satellite-derived land surface, atmospheric, and hydroclimatic indicators within a cloud-based environmental computing framework. In details, it identifies a consistent pattern of vegetation decline, built-up surface expansion, surface warming, and increasing atmospheric pollutant and greenhouse gas concentrations during the early phase of urban development. The observed vegetation dynamics and rainfall variability further indicates that recent environmental changes in IKN are increasingly driven by anthropogenic land transformation rather than natural climatic fluctuations.

Although IKN has not yet developed the full morphological and thermal characteristics of a mature urban heat island, the trends in NDVI, NDBI, Land Surface Temperature, and atmospheric indicators provide robust early-warning signals of a transition toward a heat-prone urban environment. The continued land clearing, surface sealing, and emission growth may increase long-term thermal risk, particularly under tropical climatic conditions and ongoing global warming.

These findings underscore the importance of embedding environmental computing and continuous satellite-based monitoring into the planning and governance of IKN. Proactive and data-driven interventions—such as preserving urban vegetation, managing impervious surface expansion, and controlling emissions from construction and transportation—offer a critical opportunity to prevent persistent urban heat stress and to ensure that IKN evolves as a climate-resilient, low-emission, and health-supportive tropical capital.

5. Conflict of Interest

The authors declare no competing financial or personal interests, conducted the research independently without commercial sponsorship, and confirm adherence to ethical research practices.

6.Acknowledgments

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7. References

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