DOI: https://doi.org/10.5821/siiu.12896

URBANISATION ALONG THE NILE'S CANYON-DELTA JUNCTION
A remote-sensing approach to permeability and urban form in Greater Cairo

Aleix Saura Vallverdú

Laboratori d'Urbanisme de Barcelona (LUB). Department of Urbanism, Territory and Landscape (DUTP) at the Barcelona School of Architecture (ETSAB)-Universitat Politècnica de Catalunya - BarcelonaTech (UPC)

aleix.saura@upc.edu ORCID: 0009-0006-7291-7370

ABSTRACT
The rise of Cairo as a megalopolis in the last four decades has caused a division of the Nile's canyon and delta ecosystems, as the city grows in the key region where one ecosystem shifts onto another. Urban development has impermeabilized this juncture, losing crucial eco-system benefits as the river's environmental continuity is undermined. A remote-sensing, decade-by-decade study offers the opportunity to gain a comprehensive understanding of the changes undergone by the city, which are then contrasted with a granular analysis of the specific developments that explain Cairo's expansion. Highlighting key urban phenomena in relation to the whole, the logics behind the urbanisation of this territory can surpass a binomial study of built or fertile, as "mixed" urban green spaces further the debate on the importance of the restoration of the Nile as a green corridor.

Keywords: MENA, territorial analysis, green infrastructure, NDBI.
Topic*:* análisis y ordenación del paisaje/territorial analysis and landscape management.

1. Introduction: a cohesive, ecosystemic view of granular urban changes

Cairo occupies a unique position on the course of the Nile, at the crossroads between the green canyon of the Sahara and the wetlands of the delta as the river fans out towards the sea. In total, the Nile ecosystem accounts for 5% of Egypt's land area, yet it is home to 95% of its population, most of whom live in the megalopolis of Cairo, with its 22 million inhabitants.

Over the past four decades, Cairo has become one of the world's leading metropolises (IAURIF, 1984), consuming in its wake the fertile plains to its west, despite attempts to contain growth on limited agricultural land, as seen in Cairo's 20th century master plans (El Kadi, 1990) with their insistence on “infrastructure as a container” and satellite cities built on the desert.

However, the encroachment on fertile land should be seen not only as an issue of provisioning, but as one that limits the city's ecosystem services as a whole: Cairo has imposed an ecological blockade on the Nile, dividing the river environment into canyon and delta.

This blockade, consolidated in the 1980s, is made impervious by the consumption of permeable soils (Peleman et al., 2022; Viganò et al., 2020; Youssef et al., 2020), separating the Nile ecosystems both on surface and in section, as the groundwater is sealed from the surface, the temperature of the latter rises due to the urban heat island effect of heat absorbed by concrete and asphalt (Viganò et al., 2016).

To understand the process of impermeabilization at this territorial juncture, remote-sensing methodologies are employed to obtain a cohesive view of the specific urban processes that granularly change the city. The main objective of this work is to test the correlation between remote-sensing methodologies and the process of urbanisation that has led to the impermeabilization of the transition zone between the ecosystems of canyon and delta in the Nile environment, creating an “urban cut-off” effect.

Furthermore, despite said blockage, it is hypothesized that although conventional remote-sensing studies showcase a binomial built/unbuilt approach, it is possible to highlight the potential of “mixed” surfaces, those at the boundary between fertile and bare, which can articulate a potential green infrastructure within the city, and act as a green corridor for the Nile. As such, “mixed” is added extra category between fertile and urban (and water) to analyse the relation of these spaces with the city, and study their behaviour along the city’s changes.

2. Methodology

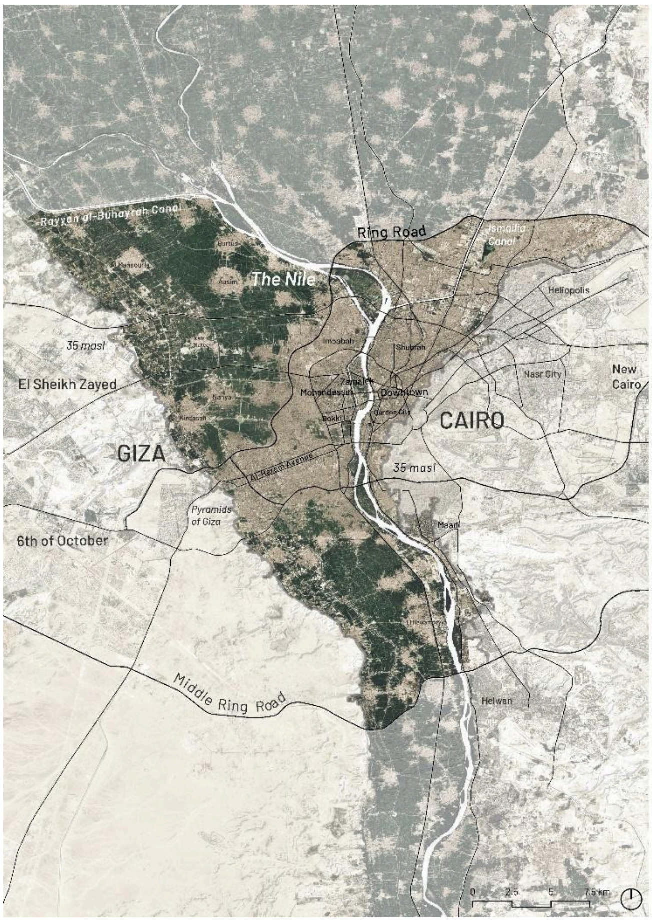
The area of study is analysed by means of contrasting urban phenomena with a remote-sensing study that tracks their development via imperviousness. Tools such as the Imperviousness Density Dataset (Copernicus-CLMS, 2020) contribute in the understanding of soil functions and built-up changes.

However, these and other studies are unavailable in Egypt, as access to precise, contemporary cartography is limited (Sims & Mitchell, 2015, p. 15). Instead, the use of multi-spectral global satellite imagery (available since the 1980’s) is an accurate way to visualise Cairo’s environment and study its changes.

In this study, satellite data is processed using the Normalized Difference Built-up Index. Proposed by Zha et al. (2003), it was developed to determine the extent of impervious and urban areas and vegetated and waterbodies. NDBI has now become standard, previously used in several recent studies realized throughout Egypt which focus on assessing built-up impact in causing the urban heat island effect (Abd el-Kawy et al., 2019; Aboelnour & Engel, 2018; Abou Samra, 2023; Tabet et al., 2023).

DOI: https://doi.org/10.5821/siiu.12896

2.1. On the area of study



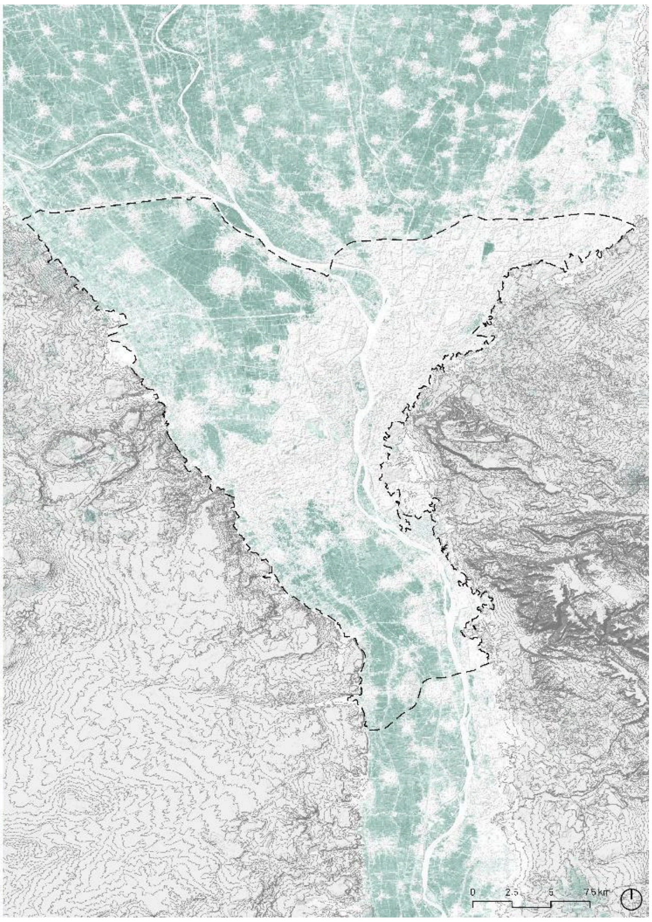


Fig. 01 Area of study and main urban elements. Fig. 02 Biophysical transition between canyon and delta, limited by the 35 *masl* line. NDVI study and DEM data obtained from Copernicus Sentinel-2 MSI, 2020.

The area of study (Fig. 01) covers 574.2 km^2 divided between the Governorates of Cairo, Giza and Qalyubia, encompassing 21% of the Greater Cairo Area. It is located at the transitional space (Fig. 02) between the two ecosystems in the Nile's path throughout Egypt: its 900km long canyon (Upper Egypt) and its 150km long delta (Lower Egypt).

This transitional ecotone is defined by a sharp edge with the desert to its east and west, associated with the contour line 35 meters above sea level, inferred in modern times through ortho-photography, soil maps and ground-water maps (Abdel Rahman Attia, 1999; EIA, 2010; El-Nahrawy, 2011; RIGW/IWACO, 1989) and historical cartography, to understand how built-up areas were once part of this ecosystem.

Northern and southern limits are ambiguous due to the continuity of the riverine environment. Instead, man-made structures that cut across it are employed as borders: 1) Northwards, the major canal of Rayyan al-Buhayrah and the Ring Road. 2) Southwards, the Ring Road was not a limiting factor, as settlements such as Maadi and Helwan were located outside its perimeter. Therefore, the much newer Middle Ring Road is employed as a cut-off.

DOI: https://doi.org/10.5821/siiu.12896

2.2. On the timeframe

The years chosen for analysis coincide with several significative events in the modern development of the city of Cairo, such as: 1) 1984: a rising Cairo as one of the world's metropolises (IAURIF, 1984), and the launch of Landsat 05 2) 1995: in the wake of the 1992 earthquake, the desert settlements fail their population targets, as government reconciles with the informal 3) 2004: Completion of the Ring Road, and consolidation of the informal dynamics of soil consumption 4) 2015: Following political turmoil, an unprecedented housing boom looms over the delta 5) 2023: New motorways criss-cross the delta following the 2022 relocation of the capital 45 kilometres east of Cairo.

2.3. On the study of urban changes

The main drivers of urban change are examined in parallel to a decade-by-decade remote sensing approach, to understand the urbanisation of the area of study between 1984 and 2023. Whilst considering the impact of pre-existing traces (such as Al-Haram Avenue, the old colonial road connecting the city with the Pyramids), urban phenomena are examined in detail: the implementation of the 1982 Master Plan by GOPP and IAURIF, which aimed to curtail the growth on fertile areas via new road infrastructure towards several desert settlements. In contrast to that, informal housing construction on fertile land and its dynamics are examined, as are the densification of the central city and the loss of its "mixed" urban green spaces, and the multiplication of the city's road infrastructures.

2.4. On the remote-sensing approach

NDBI is based on the principle that built-up and bare areas reflect more short-wave infrared (SWIR) radiation than near-infrared (NIR) when compared to vegetation (Alhawiti & Mitsova, 2016) (Alhawiti & Mitsova, 2016). The index is calculated using the following equation (Zha et al., 2003):

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

The resulting images are classified on a -1 to 1 scale, with the classes being: 1) Waterbodies, 2) Fertile, 3) Mixed (close to 0), and 4) Urban and bare.

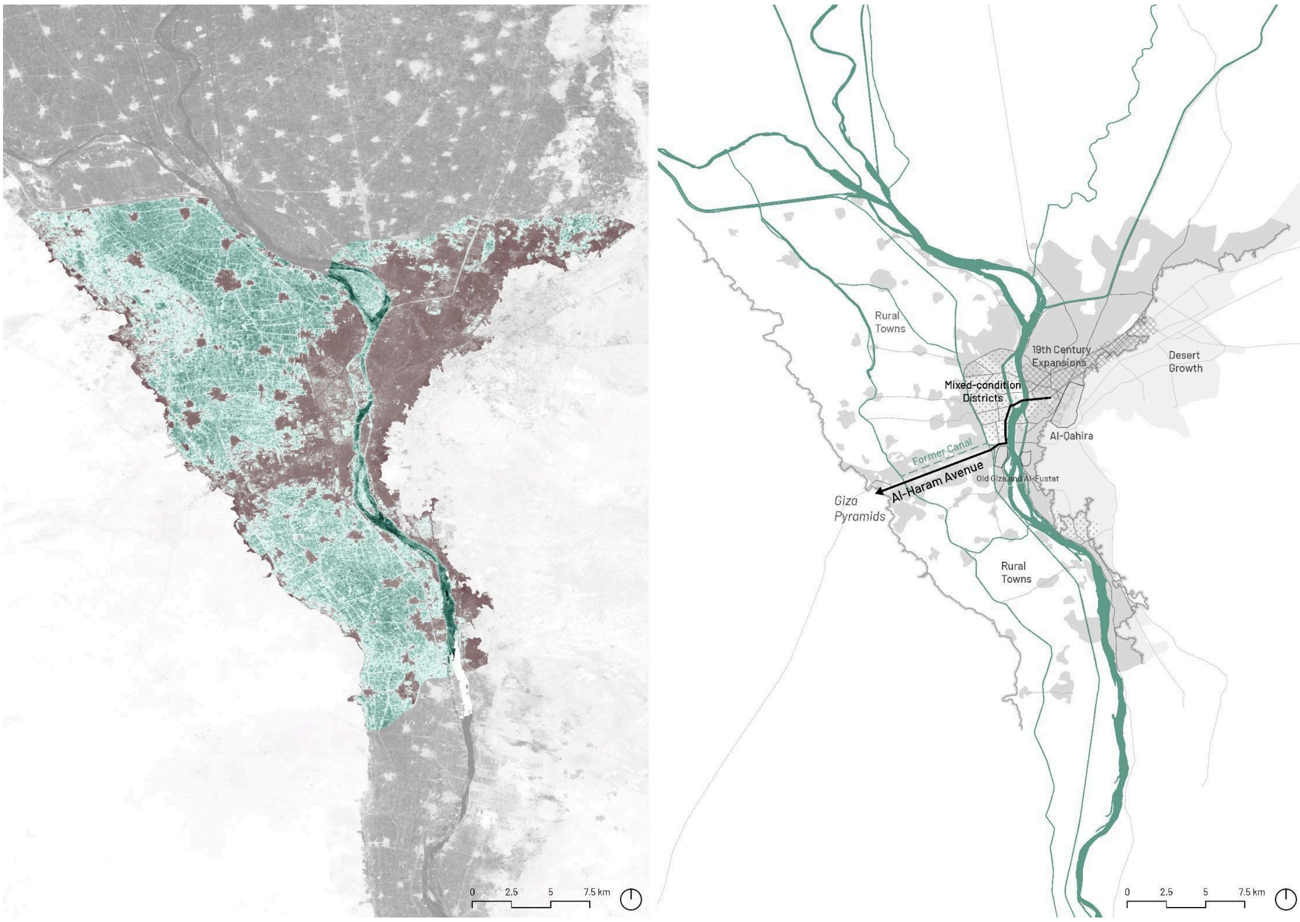
The datasets used use different satellite collections: 1) the 1984 and 1995 images use the USGS Landsat 5 Surface Reflectance Tier 1 collection 2) the 2004 data use the USGS Landsat 7 Surface Reflectance Tier 1 collection 3) the 2015 and 2023 images use the Copernicus Sentinel-2 Multi-Spectral Instrument collection. The higher spatial resolution of the newer Sentinel-2 collection (10 metres per pixel compared to the 30 metres of the Landsat collections) allows more detailed changes to be seen in the last two periods.

Confusion over the distinction between bare (desert) land and urban areas is reduced by the selection of the study area: it is limited to the confines of the Nile's shallow aquifer, which has a continuous agricultural carpet. Nevertheless, the images to be analysed were taken in winter, during the harvest season, to accurately represent fertile areas (El-Nahrawy, 2011). To minimize the impact of crop rotation, a visual interpretation process was employed, following the methodology proposed by Abd el-Kawy et al. (2019). Remaining shadows and clouds were filtered and masked to improve the analysis accuracy. Finally, the image collections were harmonized despite different input technologies.

DOI: https://doi.org/10.5821/siiu.12896

3. An urban “cutoff” between canyon and delta

3.1. 1984 and precedents: A rising metropolis



Surface Distribution	Waterbodies	Fertile	Mixed	Urban
1984	35.6 km^2 (6.2%)	344 km^2 (59.9%)	34.4 km^2 (6.0%)	160.2 km^2 (27.9%)

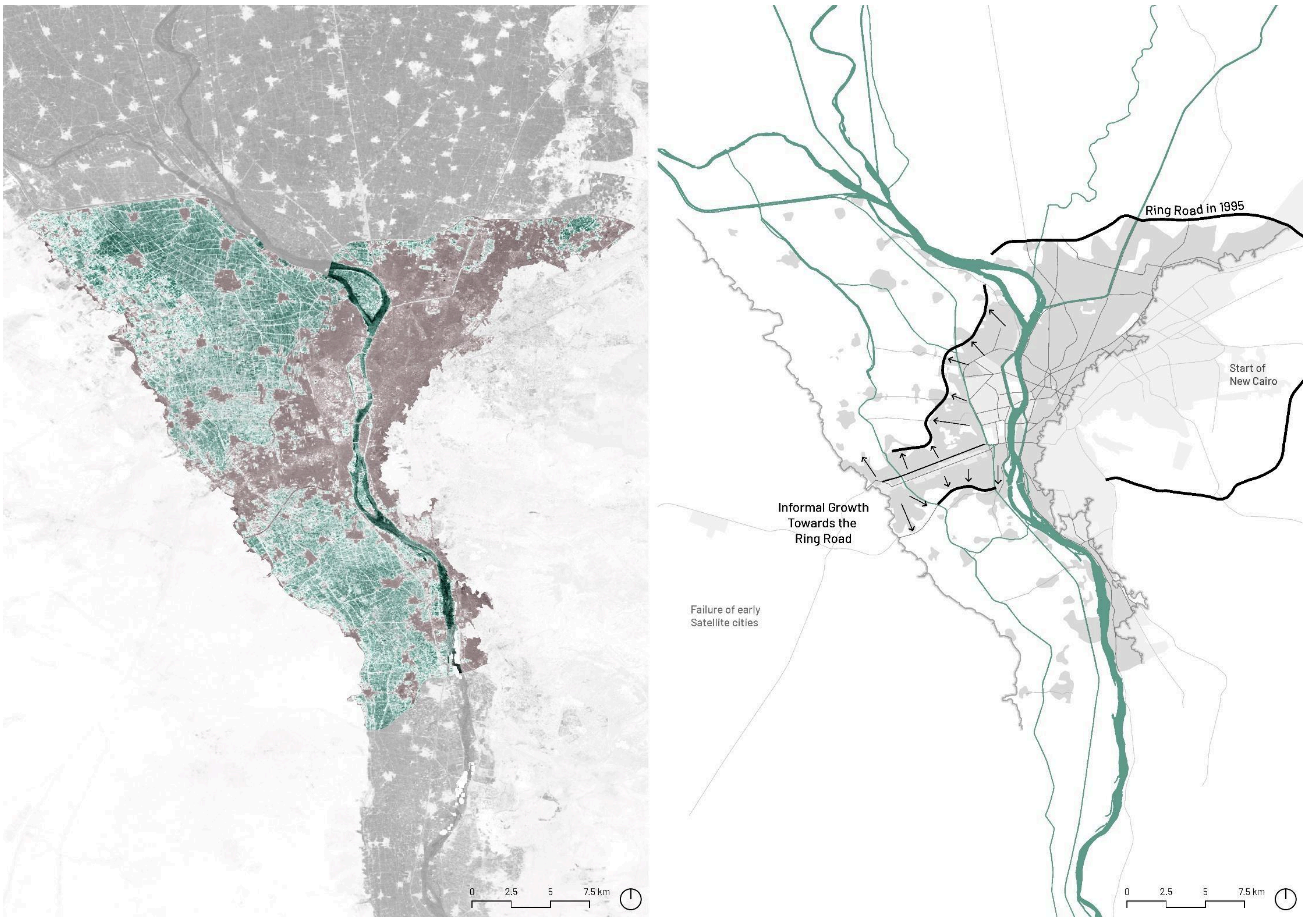
Fig. 03 1984 NDBI study. Data from USGS Landsat 5 SR T1.
Tab. 01 Surface distribution in 1984.

The increase of urbanised area at the start of the 1980’s was evenly split between desert and arable land at the same rate of 600ha yearly, accelerating the loss of the delta surface from previous decades (Aga Khan, 1985, p. 100). With the same amount of population as Paris in three times less the surface (IAURIF, 1984, p. 131), the city of Cairo in 1984 was one of the world’s foremost metropolises, as highlighted the *Symposium International Metropolis 84* (IAURIF, 1984), with 11 million people, of which 2 million lived in “isolated towns” and “a rural area”.

Through this metropolitan condition, Fig. 03 showcases all the features that define its growth over the Nile’s banks: a compact and built-up eastern bank resulting from 19th century Hausmannian expansions; somewhat lower density upper-class districts close to the river and directly next to the western bank (Garden City, Zamalek, Mohandessin, Dokki) – the backbone of most of the “mixed” urban areas – and adjoining lower class districts of extreme density, with compact villages amidst the hinterland (known as “informal settlements”); the old road connecting the city with the Pyramids, now Al-Haram Avenue, is the noticeable exception to the rule, an unbridled corridor for expansion, linking the city with the new satellites to its west.

DOI: https://doi.org/10.5821/siiu.12896

3.2. 1995: An unsuccessful check against rural growth



Surface Distribution	Waterbodies	Fertile	Mixed	Urban
1995	36.4 km^2 (6.3%)	319.9 km^2 (55.7%)	30.7 km^2 (5.4%)	187.2 km^2 (32.6%)

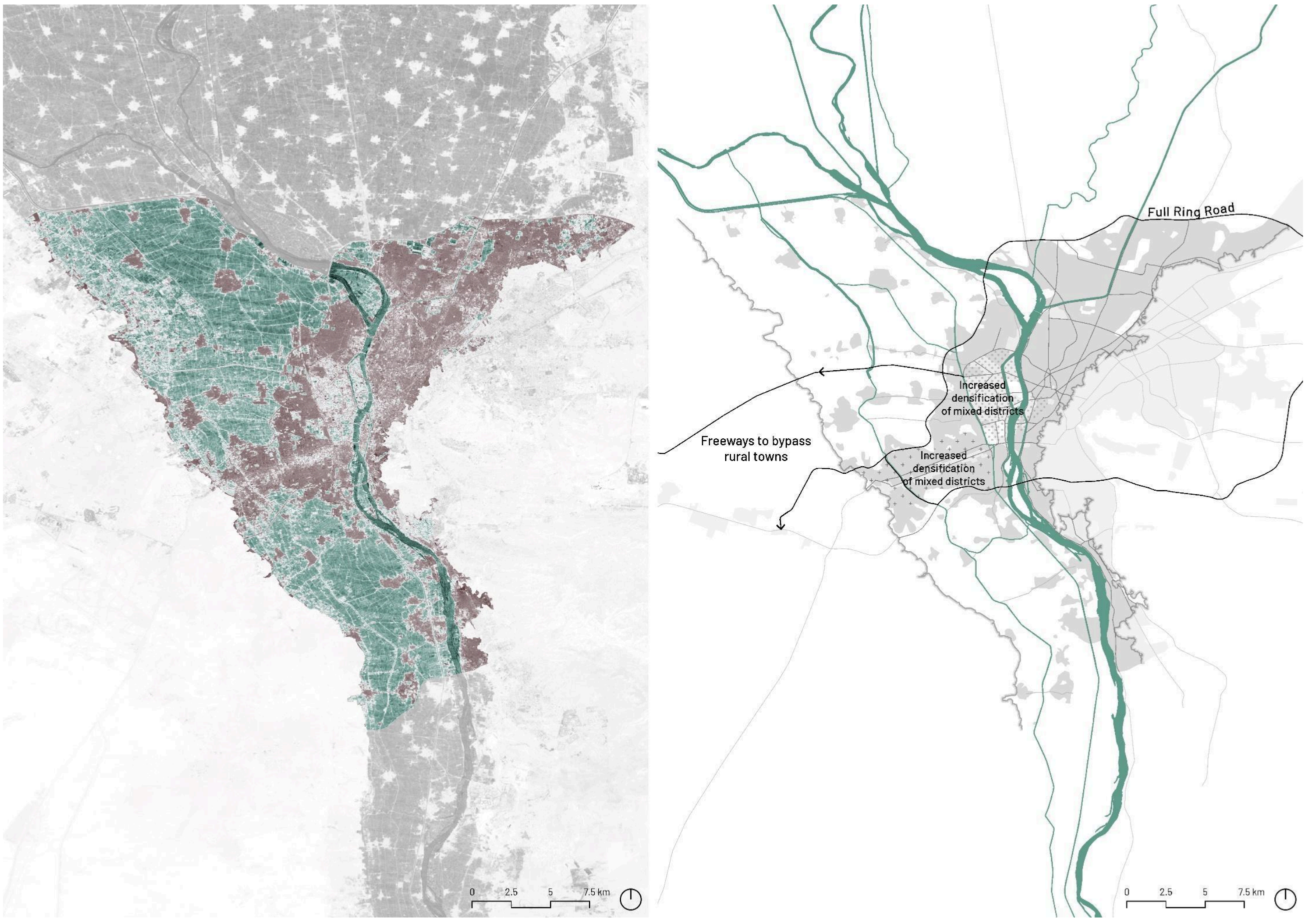
Fig. 04 1995 NDBI study. Data from USGS Landsat 5 SR T1.
Tab. 02 Surface distribution in 1995.

The implementation of the 1982 GOPP and IAURIF Master Plan (containment of urban growth through a “Ring Road” and its redirection towards desert settlements), had failed in its objectives as desert cities barely attracted 100,000 inhabitants, whereas informal settlements accounted for 24% of the metropolis’s urban area (El Kadi, 2012, p. 106). As shown in Fig. 04, the planned Ring Road would not become wall, but a key urban structure of the city, defining its built-up area, and provide points of increased accessibility close to its interchanges, from which further growth would continue.

The 1992 earthquake shifted government policy from public housing to the recognition and upgrading of informal housing districts, especially those near Al-Ahram, which presents significant growth as seen in Fig. 04 (El-Batran & Arandel, 1998). Despite their name, “informal settlements” substituted fields wholesale as canals became streets (Joshi & Tonarelli, 2016), with neighbourhoods featuring incredible densities (over 100,000 inhabitants per km^2). Government policy of that period serviced already mature conglomerations with water, electricity and sewage, yet public facilities were lacking. This need formed pendular movements via community-organised transport services for healthcare, education, and work, mostly towards the central city (Sims, 2012).

DOI: https://doi.org/10.5821/siiu.12896

3.3. 2004: Densification of the new perimeter



Surface Distribution	Waterbodies	Fertile	Mixed	Urban
2004	37.9 km^2 (6.6%)	291.1 km^2 (50.7%)	40.2 km^2 (7.0%)	205.0 km^2 (35.7%)

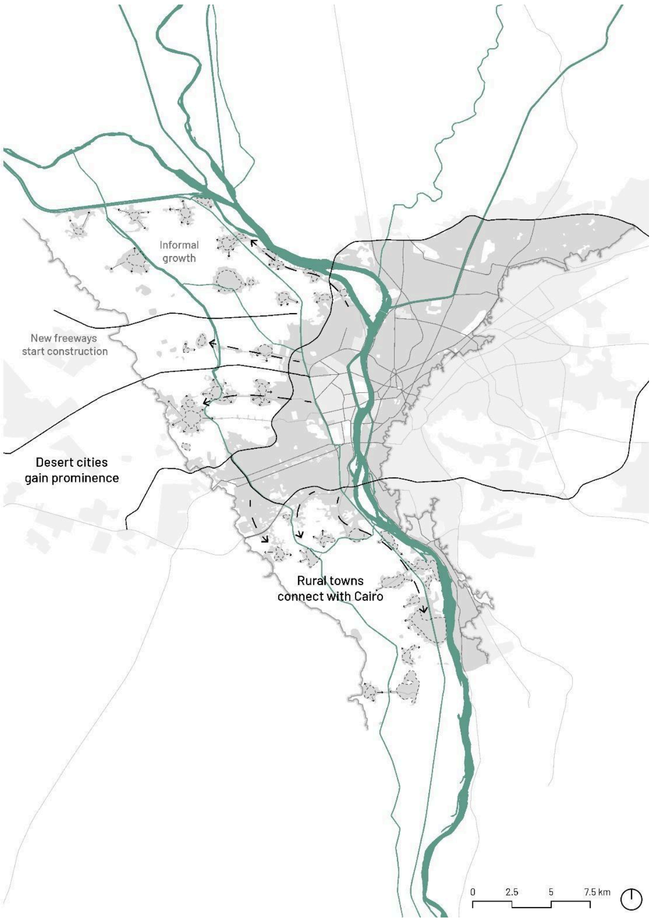
Fig. 05 2004 NDBI study. Data from USGS Landsat 7 SR T1.
Tab. 03 Surface distribution in 2004.

The Ring Road project was almost complete, and yet the informal settlements which it had to contain were now seen as a contribution to a rising housing crisis (El-Batran & Arandel, 1998, p. 231): liberalisation tactics saw a halving of public housing construction, but private enterprises did not fill its expected role as a replacement. As a result, the Ring Road's perimeter, previously agricultural fields, was almost entirely built-up, as the growth adjoined to the central districts and Al-Ahram avenue had consolidated beside it.

Lack of interest of private investment in the housing market is partly explained by an overabundance of stock, with as many as 7 million empty homes in 2006 (Shawkat, 2020, p. 115). This is linked to a loss of population in the central areas, as seen in the census of 1996 and 2006, in favour of the rural periphery or segregated satellite cities. Tertiary space became a more attractive investment, as a significant amount of gardens and empty manors were replaced by compact office buildings in the districts closest to the western bank of the Nile (El Kadi, 2012, p. 114). Still, the finer grain of the newly released Landsat 07 data was nevertheless able to capture a substantial amount of "mixed" urban green spaces.

DOI: https://doi.org/10.5821/siiu.12896

3.4. 2015: Explosive growth on the countryside



Surface Distribution	Waterbodies	Fertile	Mixed	Urban
2015	37.2 km^2 (6.5%)	243.5 km^2 (42.4%)	63.1 km^2 (11.0%)	230.4 km^2 (40.1%)

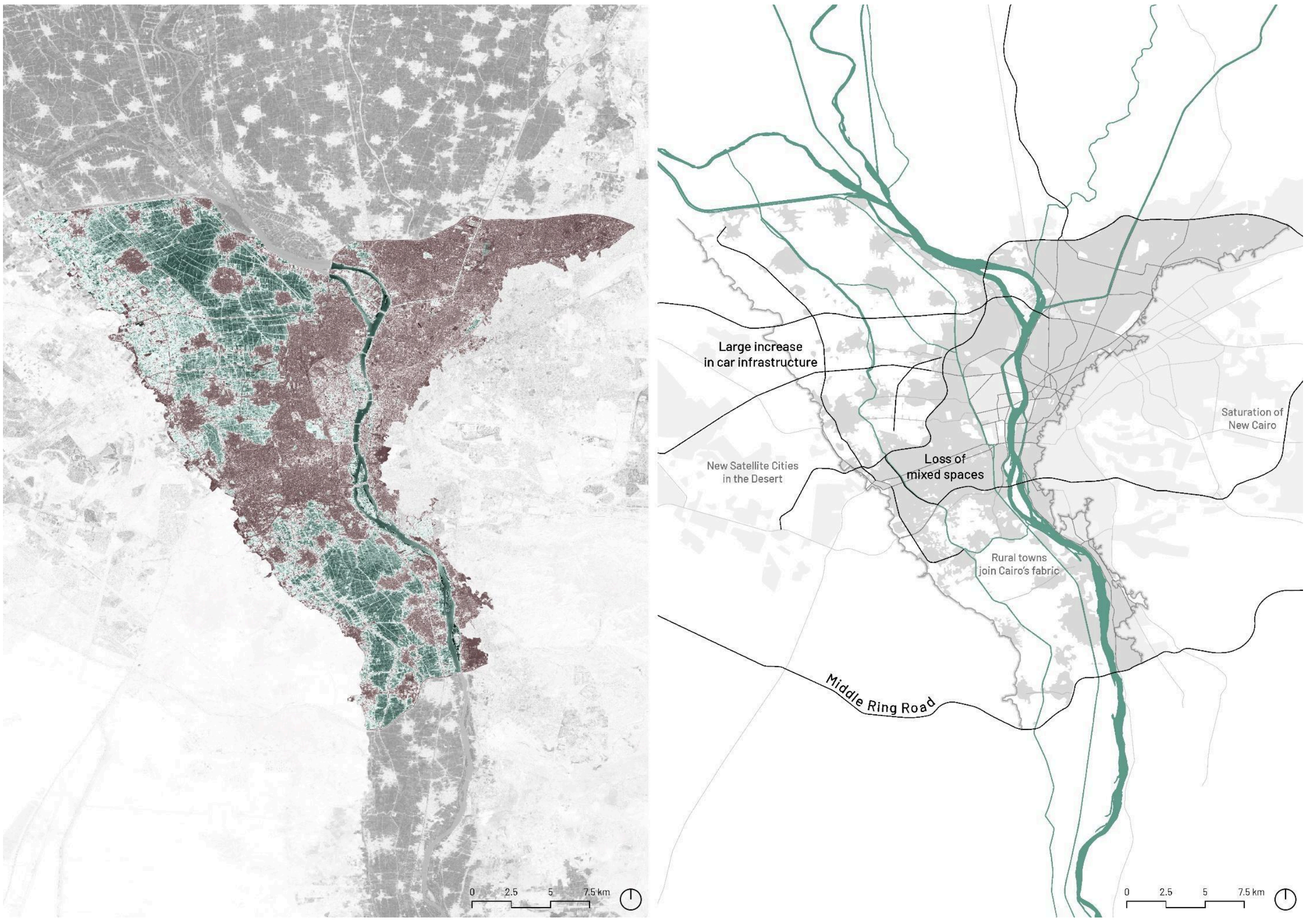
Fig. 06 2015 NDBI study. Data from Copernicus Sentinel-2 MSI.
Tab. 04 Surface distribution in 2015.

Despite the political upheaval experienced in the early years of the 2010 decade, the accelerated increase in urban land observed in Figure 06 is supported by statistical data, as Egypt became one of the largest producers of housing units in the world (Shawkat, 2020, p. 51). Furthermore, as can be observed in the data collected in the NDBI study, between 2015 and 2016 the balance between urban and fertile land was reversed in favour of urban land in the area of study, as the settlements of the Delta expanded. The increase in “mixed” areas can be attributed to the rural-to-urban transition seen in the expanding perimeter of urbanised informal areas around the city and nearby towns. The observed urban dominance is consistent with the trend seen in the 2017 Housing Stock Census, where informal dwellings outnumbered formal dwellings for the first time since the first regular census in 1960 (CAPMAS, 2017).

DOI: https://doi.org/10.5821/siiu.12896

In parallel, it is during the 2010 and 2020 that an increasing number of motorways begin to cross the area of study, a renewed effort in linking desert settlements with the core city. Parallel to the 26th of July corridor (already present in Fig. 05), the Rod El-Farag axis is one such example.

3.5. 2023: Proliferation of car infrastructure



Surface Distribution	Waterbodies	Fertile	Mixed	Urban
2023	35.9 km^2 (6.3%)	206.3 km^2 (35.9%)	67.9 km^2 (11.8%)	264.1 km^2 (46.0%)

Fig. 07 2023 NDBI study. Data from Copernicus Sentinel-2 MSI.
Tab. 05 Surface distribution in 2023.

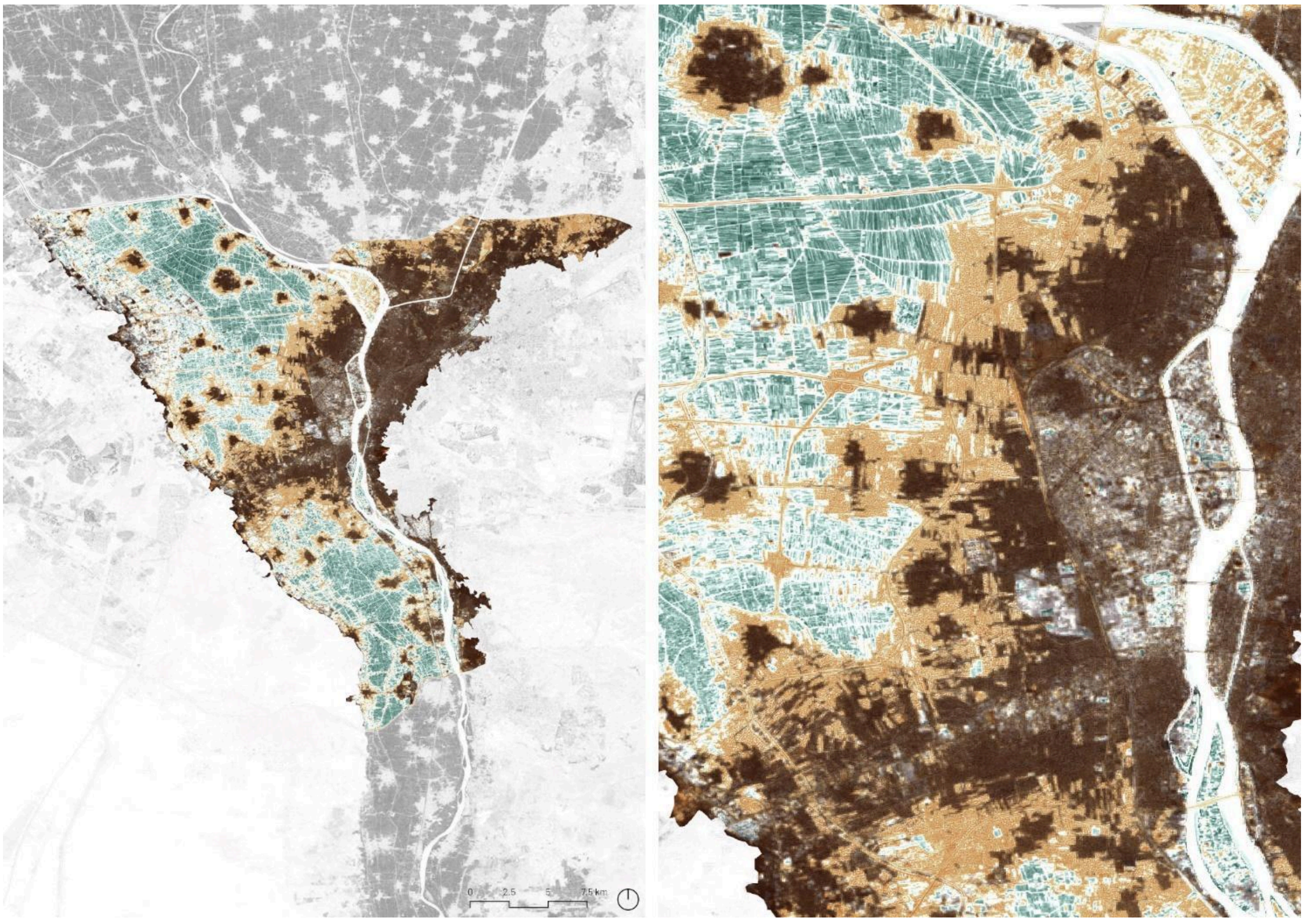
The construction of motorways accelerates, as a plethora of new corridors and belts make their way across both agricultural fields and informal settlements. The displacement of the capital to the desert in 2022 has not seemed to slow down the construction of car infrastructure in present Cairo, which now is home to more than 22 million people.

Furthermore, pre-existing avenues and roads within the city and the delta see its greenery removed in a bid to increase their width to make space for cars, as canals exchange tree-lined avenues for two-lane motorways, as detected in the NDBI study: Fig. 07 showcases the change, from the deep green of a water-body and greenery to shades of red and white of impervious car infrastructure, wider than the still remaining water-body

DOI: https://doi.org/10.5821/siiu.12896

of the canal itself. This is also visible within the city's fabric, as a significant decrease of green spaces along the main thoroughfares and central spaces (such as Azbakeya and Al-Haram) is noticeable (Crosas & Saura, 2022), inflicting a loss of eco-systemic benefits, as urban surfaces approach the 50% threshold within the area of study.

4. Conclusion



Surface Distribution	Waterbodies	Fertile	Mixed	Urban
1984	35.6 km^2 (6.2%)	344 km^2 (59.9%)	34.4 km^2 (6.0%)	160.2 km^2 (27.9%)
1995	36.4 km^2 (6.3%)	319.9 km^2 (55.7%)	30.7 km^2 (5.4%)	187.2 km^2 (32.6%)
2004	37.9 km^2 (6.6%)	291.1 km^2 (50.7%)	40.2 km^2 (7.0%)	205.0 km^2 (35.7%)
2015	37.2 km^2 (6.5%)	243.5 km^2 (42.4%)	63.1 km^2 (11.0%)	230.4 km^2 (40.1%)
2023	35.9 km^2 (6.3%)	206.3 km^2 (35.9%)	67.9 km^2 (11.8%)	264.1 km^2 (46.0%)

Fig. 08 1984-2023 NDBI study comparison. Data from USGS Landsat 5 SR T1, Copernicus Sentinel-2 MSI.
Tab. 06 Surface distribution aggregate.

The study has demonstrated how urban development has led to the division of the Nile canyon and delta ecosystems over the past four decades. An initial 60%-28% split in favour of fertile lands in 1984, the current proportion is 36%-46% in favour of impervious areas. Waterbodies have remained constant at 6%, while mixed areas have modestly increased, from 6% to 11%. It is postulated that mixed areas are predominantly identified at the periphery of the expanding urban area, correlating with an increasing border. Most of the mixed areas derived from the early 20th century colonial fabric continue to provide districts close to the Nile with valuable green spaces, despite losses in recent years. They also hold the potential to articulate a green corridor alongside the river. By correlating urban phenomena with remote-sensing data, the logic behind the construction at the juncture of the Nile's ecosystems can be quantified and qualified as a whole and as patterns, such as informal settlement growth, infrastructure construction and inner-city densification, tracking the transformation of key city traces. New cartographies can be generated to obtain a global vision of the granular changes experienced by the city throughout the years (Fig. 08), thus enabling an understanding of their effects on the city's environment, gathering evidence for a greener, more sustainable future.

References

ABD EL-KAWY, O. R. et al. (2019). Temporal detection and prediction of agricultural land consumption by urbanization using remote sensing. *Egyptian Journal of Remote Sensing and Space Science*, *22*(3), 237–246.

ABDEL RAHMAN ATTIA, F. (1999). Water and Development in Greater Cairo (Egypt). *Revista CIDOB d'afers Internacionals*, *45*, 81–102.

ABOELNOUR, M., & ENGEL, B. A. (2018). Application of Remote Sensing Techniques and Geographic Information Systems to Analyze Land Surface Temperature in Response to Land Use/Land Cover Change in Greater Cairo Region. *Journal of Geographic Information System*, *10*(01), 57–88.

ABOU SAMRA, R. M. (2023). Investigating and mapping day-night urban heat island and its driving factors using Sentinel/MODIS data and Google Earth Engine. *Urban Climate*, *52*(October).

AGA KHAN. (1985). Cairo, 1800 2000: Planning for the Capital City in the Context of Egypt's History and Development. *Expanding Metropolis: Coping with the Urban Growth of Cairo*, *9*, 91–120.

ALHAWITI, R. H., & MITSOVA, D. (2016). Using Landsat-8 Data To Explorethe Correlation Between Urban Heat Island and Urban Land Uses. *International Journal of Research in Engineering and Technology*, *05*(03), 457–466.

CAPMAS. (1996). *General Census for Population, Housing and Establishments*.

— (2006). *General Census for Population, Housing and Establishments*.

— (2017). *General Census for Population, Housing and Establishments*.

COPERNICUS-CLMS. (2020). *Imperviousness Density Layer 2018*.

CROSAS, C., & SAURA, A. (2022). The shaping of a central hub: Stories and maps on Attaba-Azbakeya-Opera. In C. Crosas (Ed.), *Attaba - Vibrant Hubscape in Central Cairo* (pp. 12–66). Laboratori d'Urbanisme de Barcelona / RU Books.

EIA. (2010). *Study for Greater Cairo Metro Line No . 4 Final Report.* National Authority for Tunnels, EIA Study for Greater Cairo Metro Line No . 4.

EL-BATRAN, M., & ARANDEL, C. (1998). A shelter of their own: Informal settlement expansion in Greater Cairo and government responses. *Environment and Urbanization*, *10*(1), 217–231.

EL-NAHRAWY, M. A. (2011). *Country Pasture/Forage Resource Profiles (Egypt)*.

EL KADI, G. (1990). Trente ans de planification urbaine au Caire. *Tiers-Monde*, *31*(121), 185–207.

— (2012). *Le Caire: Centre en mouvement* (Y. Cavallazzi (ed.)). IRD Éditions Institut de recherche pour le développement.

IAURIF. (1984). Symposium International Metropolis. 19 Grandes Métropoles en bref. *Les Cahiers de l'Institut* *d'Amenagement et d'Urbanisme de La Region d'Ile-de-France*, *74*, 4–61.

JOSHI, A., & TONARELLI, F. (2016). SUB-DIVIDING EGYPT Process of Land Management and Development. In M. Angélil & C. Malterre-Barthes (Eds.), *Housing Cairo* (pp. 66–75). Ruby Press.

PELEMAN, D., MARTINA BARCELLONI-CORTE, RONNER, E., & VIGANÒ, P. (2022). Editorial introduction on the issue. *OASE*, *110*.

RIGW/IWACO. (1989). *The Hydrogeological Map of Cairo*. Research Institute for Groundwater.

SHAWKAT, Y. (2020). *Egypt's Housing Crisis The Shaping of Urban Space*. The American University in Cairo Press.

SIMS, D. (2012). *Understanding Cairo, The Logic of a City without control*. The American University in Cairo Press.

SIMS, D., & MITCHELL, T. (2015). *Egypt's Desert Dreams: Development or Disaster*. American University in Cairo Press.

TABET, A. A., ABDAOUI, G. R., & LAYEB, H. (2023). Automatic extraction of build-up areas from bare land using Sentinel 2A imagery in El Khroub city, Algeria. *Bulletin de La Société Royale Des Sciences de Liège*, *92*(1), 1–22.

VIGANÒ, P., BARCELLONI CORTE, M., & VIALLE, A. (2020). Le sol de la ville-territoire. *Revue d'anthropologie Des Connaissances*, *14*(4).

VIGANÒ, P., SECCHI, B., & FABIAN, L. (2016). *Water and asphalt. The Project of Isotropy in the Metropolitan Area of Venice*. Park Books.

YOUSSEF, A., SEWILAM, H., & KHADR, Z. (2020). Impact of Urban Sprawl on Agriculture Lands in Greater Cairo. *Journal of Urban Planning and Development*, *146*(4), 1–12.

ZHA, Y., GAO, J., & NI, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing - INT J REMOTE SENS*, *24*, 583–594.