



Land degradation and restoration case studies

(selected problems / examples from around the world)

Okavango, Botswana (Cubango in Angola, Kavango in Namibia) catchment

- interesting river (Okavango) with an inland delta; the river “empties” into large swamp / wetland area in Botswana surrounded by Kalahari desert
- it is a biodiversity hub of global relevance
- it provides important ecosystem services: fresh-water, water purification, crops, fish, wildlife, fuel, timber, fiber and forage
- population is growing in the region and the rural people adopt a ‘modern’, consumption-driven lifestyle
- deforestation coupled with cropland area increase in the upper part of the catchment has led to enlargement of the land struck by erosion
- agriculture in the region is largely based on a shifting cultivation system with slash-and-burn techniques for field clearing and, after a period of cultivation, long-term fallows of several decades for the regeneration of soil fertility
- the main crop in the study area is maize (it is one of the worst crops when it comes to erosion, because of large spans / openings between the plants → more soil is exposed to rainfall)
- every 5 to 10 years (depending on soil fertility), the areas are abandoned as the farm moves deeper into the forest to clear a new patch of forest for the establishment of its next cultivation area

Sandy lands, Inner Mongolia, China

- agro-pastoral zone between the Inner Mongolian Plateau and the Northeast Plains in China
- before intensification of agriculture, sand dominated ecosystems in Inner Mongolia had been supporting a traditional and sustainable nomadic production system; sandy dunes and plains covered by drought resistant shrubs and grass species provided top-quality pasture for sheep grazing
- with growing population in China much of pastures and shrublands were converted to croplands
- consequences: significant increase of erosion (mostly wind erosion) and decline in soil productivity (after 2 or 3 years of cultivation)
- perhaps the most striking consequence is decrease of groundwater recharge, since the sandy soils (with low water retention capacity) require much water for providing the crops in sufficient amounts
- excessive use of groundwater for irrigation purposes has led to successive retreat of lakes, ponds, bogs and wetlands in the region

Aral Sea, Kazakhstan / Uzbekistan

- at around 67 500 km in 1960, the Aral Sea was the world's fourth-largest inland water body. It is a terminal lake, mainly fed by two rivers, the Amu Darya and the Syr Darya, which stem from the snowfields and glaciers of the Pamir and Tian Shan mountains
- located in arid climate, the extent of the Aral Sea depends on the equilibrium between annual fresh-water inflow and evaporation
- as a brackish lake with salinity averaging near 10 g/L, the lake was home to freshwater fish species, supporting a major fishery industry
- irrigation was practiced in the Aral Sea basin for millennia without substantially diminishing inflow to the Aral Sea. However, with the introduction of large-scale irrigation systems in the early 1930s, traditional and sustainable water-management systems within the region were largely destroyed
- between 1960 and 1980 the cotton acreage in central Asia expanded; in Uzbekistan alone, cultivated lands increased from 1.3 million to 2.1 million ha, with increasing volumes of Amu Darya and Syr Darya river water being used for irrigation, annual water inflow decreased markedly → by September 2011 the lake had separated into four parts, with shrinkage in its total aggregate area (85 %) and volume (92 %) → increase in water salinity 100 g/L (10 x)

Aral Sea, Kazakhstan / Uzbekistan

- remaining water bodies are affected by pollution primarily from irrigation run-off containing salts, fertilizers, pesticides, herbicides and cotton defoliants
- these risk/toxic substances are present in dust covering the dried bottom of the Aral Sea and winds are transporting these toxic compounds across the region → respiratory illnesses
- substantial dioxin residues have been found in mothers' milk, and waterborne diseases such as typhus, paratyphoid and viral hepatitis have increased enormously over the past decades
- there have been some improvements of local environment recently
- with help from the World Bank, the Kok-Aral dam was built in 2005 in Kazakhstan to retain water from the Syr Darya in the Small Aral Sea, once a bay of the original lake in the north
- the conditions have improved within this smaller part of the Aral Sea, with positive changes in biodiversity and habitats, and increasing numbers of migratory birds, waterfowl and fish; by autumn 2011, the water salinity in the open part of the Small Sea dropped to 8-12 g/L; however, the other three main water bodies still represent hypersaline conditions
- solution: complicated, long-term and expensive; reduce irrigation in the region, the irrigation should be effective as much as possible (reduce evaporation as much as possible)

The impact of warfare on land degradation

- there are many areas around the world negatively affected warfare and residuals of weapons; land degradation is caused mainly by military actions/wars, which took place in 20th and 21st century, as older munition in general was not as abundant and chemical or nuclear weapons did not exist
- (military pollutes the environment not only in times of war but also during peace (testing the weapons, transportation))
- obvious is the physical disturbance of the landscape and infrastructure, with leaving lot of metal residues in the environment, such as Cu–Zn alloy (brass) cartridges, steel and cast-iron fragments of shells, and their corrosion products, active munition (mines, etc..) and radioactivity
- perhaps the more important are chemical consequences; the exposure to chemical weapons has very severe/serious health consequences and some of these substances or their residues persist in the environment for decades; additionally, army vehicles and machinery movement often pollute the environment by various persistent synthetic organic substances
- the wide set of xenobiotics is introduced to environment by military, including heavy metals, hydrocarbons, organic solvents, surfactants, synthetic phenols, cyanide, dioxins, and radionuclides
- the contamination by warfare is largely due to explosive compounds; explosives are mainly nitroaromatic compounds: 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), nitroglycerin, 1,3,5-trinitrobenzene (TNB), dinitrobenzene (DNB), N-methyl-N,2,4,6-tetranitroaniline (tetryl), and 2,4,6-trinitrophenol (picric acid) are some of the most frequently used, each of which shows specific environmental risks

The impact of warfare on land degradation

- nitroaromatic compounds and their degradation products have high persistence in soil due to intrinsic **recalcitrance** to volatilization, hydrolysis, and biodegradation
- they impose direct **toxic effects on soil biota** and can be **taken up root system** of edible plants
- special attention should be paid to **residues of chemical weapons** (chemical warfare agents, CWA) as they have been designed and utilized to kill, injure or incapacitate an enemy
- example: consequences of “Agent Orange” use in Vietnam; millions of liters were sprayed; this led to contamination with dioxins that are highly toxic persistent pollutants that accumulate in fatty tissues and are transferred across the food chain; not only these compounds can be transferred to children through placenta/blood or breast milk from exposed mothers, but there are also strong indications of genotoxicity of dioxins present in or derived from agent orange → toxic effects on subsequent generations

The impact of warfare (agent orange issue)

The extent and patterns of usage of Agent Orange and other herbicides in Vietnam

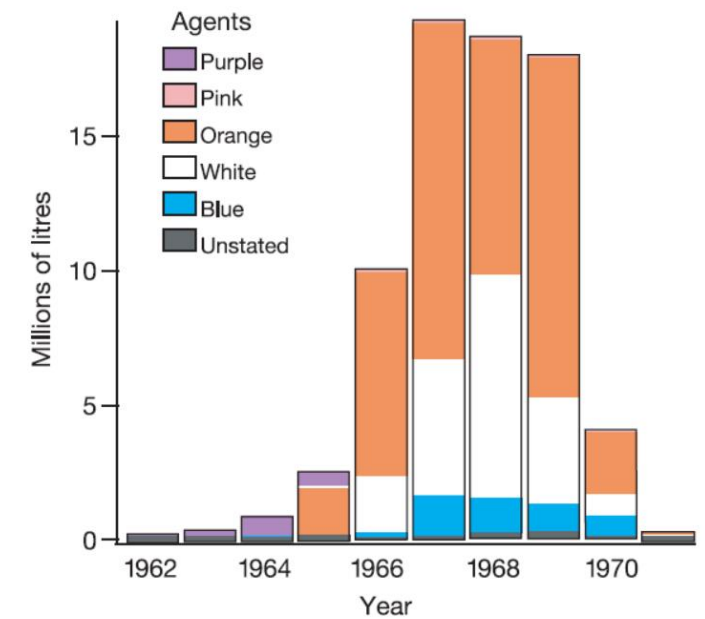
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Herbicides including Agent Orange were sprayed by United States forces for military purposes during the Vietnam War (1961–1971) at a rate more than an order of magnitude greater than for similar domestic weed control. In 1974, the US National Academy of Sciences published estimates of the extent and distribution of herbicides sprayed. Here we present revised estimates, developed using more-complete data. The spray inventory is expanded by more than seven million litres, in particular with heavily dioxin-contaminated herbicides. Estimates for the amount of dioxin sprayed are almost doubled. Hamlet census data reveal that millions of Vietnamese were likely to have been sprayed upon directly. Our identification of specific military herbicide targets has led to a more coherent understanding of spraying. Common errors in earlier interpretations of the spray data are also discussed.



Litres of herbicides sprayed over 1962–1971. The data are taken from the corrected HERBS file and do not include Dinoxol and Trinoxol used in 1961.

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Dioxin reservoirs in southern Viet Nam—A legacy of Agent Orange

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Abstract

In the isolated Aluoi Valley of central Viet Nam, very high levels of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) were measured in soil, fish fat, duck fat, pooled human blood and breast milk samples collected from A So village between 1996 and 1999. The village was situated on a former military base occupied by US Special Forces between 1963 and 1966. TCDD was a contaminant of the herbicide “Agent Orange”, aerially sprayed in the valley between 1965 and 1970, and stored at the A So base. Measured levels were lower near the sites of two other former US bases in the valley which had been occupied for shorter periods of time. In areas where Agent Orange had been applied by low-flying aircraft, levels of TCDD in soil, food and human samples were elevated, but lower than those near the three former US bases.

We confirm the apparent food chain transfer of TCDD from contaminated soil to cultured fish pond sediments to fish and duck tissues, then to humans as measured in whole blood and breast milk. We theorize that the Aluoi Valley is a microcosm of southern Viet Nam, where numerous reservoirs of TCDD exist in the soil of former military installations south of the former demilitarized zone. Large quantities of Agent Orange were stored at many sites, used in ground and aerial applications, and spilled. TCDD, through various forms of soil disturbance, can be mobilized from these reservoirs after decades below the surface, and subsequently, introduced into the human food chain. © 2002 Elsevier Science Ltd. All rights reserved.

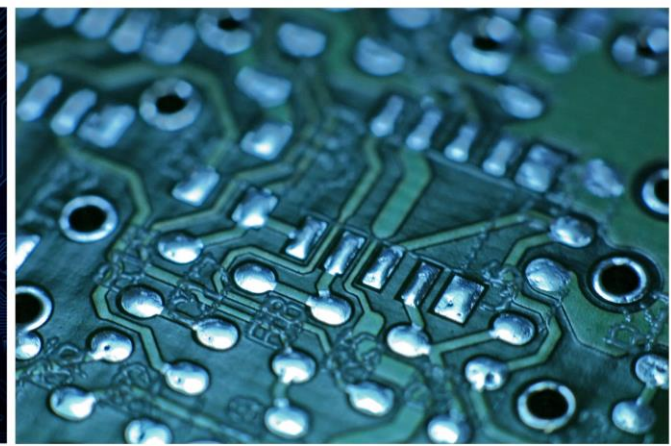
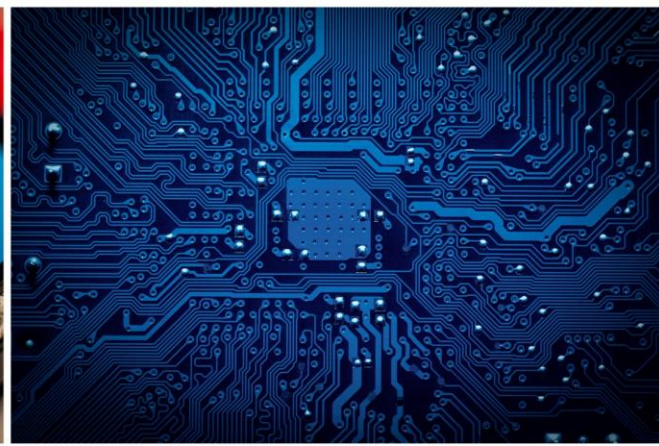
Keywords: Herbicide; 2,3,7,8-tetrachlorodibenzo-*p*-dioxin; Ranch Hand; Soil; Food; Human blood; Human milk

Sites affected by informal 'recycling' of electronic waste

- up to date the recycling of e-waste has been insufficient and not environmental
- significant amounts of e-waste have been shipped to low- and middle-income countries, such as Ghana, Nigeria, Ivory Coast, Philippines, Vietnam, Thailand, Brazil, Mexico, India or China
- crude/primitive methods are used to recover the valuables from the e-waste, resulting in negative impact on the environment
- large industrialized nations seek to set up factories abroad (pollution haven hypothesis)
- in the early stages of economic growth, pollution increase and environmental quality declines, but beyond some level of per capita income the trend reverses, so that at high income levels, economic growth leads to environmental improvement (Environmental Kuznets Curve)
- the e-waste from high-income countries, where disposal cost is high and environmental laws and regulations are strict, is often passed onto developing countries for recycling
- paradox: e-waste contains valuable metals (Cu, Au, Ag, Pd, Al, Fe,...). Based on the data from 2017 the estimated value and reserves of e-waste materials are: Fe/steel $\approx$ 16,500 kt (9 billion €), Cu $\approx$ 1900 kt (10.6 billion €), Al $\approx$ 220 kt (3.2 billion €), Au $\approx$ 0.3 kt (10.4 billion €), Ag $\approx$ 1.0 kt (0.58 billion €), and plastics $\approx$ 8600 kt (12.3 billion €). The **recycling cost** of metals from e-waste is **far below the mining of crude ore**, which means that **e-waste recycling is an energy-saving and environmentally friendly approach**. (<https://doi.org/10.1016/j.cec.2023.100028>)

Sites affected by informal 'recycling' of electronic waste

- low-cost recycling in developing countries include scavenging, sorting, crushing, open dismantling, refurbishing, open burning, acid bathing, open pit acid leaching, open dumping, selling of e-waste, and child labour
- wires covered with plastic are burnt in the open to retrieve metal; mother boards of computers are leached in acid bath to obtain resources
- **acid leaching** and the **open burning** of dismantled components, have led to the release of large quantities of **toxic metals** and **organic pollutants** into the surrounding environment
- not only e-waste contains toxic **organo-halogens** (flame retardants), but uncontrolled burning even of common PVC (covering Cu wires) produces chlorinated **dioxins** and **furans**, which are highly toxic



Agbogbloshie, Ghana, Africa

Multiple elemental exposures amongst workers at the Agbogbloshie electronic waste (e-waste) site in Ghana



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H I G H L I G H T S

- Agbogbloshie is one of the world's largest electronic waste recycling sites.
 - Little is known about human exposures to toxic elements at the site.
 - We measured As, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni, Se, Zn in 69 workers.
 - Cadmium, lead, and arsenic levels were of concern.
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A B S T R A C T

Electronic waste (e-waste) recycling is growing worldwide and raising a number of environmental health concerns. One of the largest e-waste sites is Agbogbloshie (Ghana). While several toxic elements have been reported in Agbogbloshie's environment, there is limited knowledge of human exposures there. The objectives of this study were to characterize exposures to several essential (copper, iron, manganese, selenium, zinc) and toxic (arsenic, cadmium, cobalt, chromium, mercury, nickel, lead) elements in the urine and blood of male workers ($n = 58$) at Agbogbloshie, as well as females ($n = 11$) working in activities that serve the site, and to relate these exposures to sociodemographic and occupational characteristics. The median number of years worked at the site was 5, and the average worker indicated being active in 6.8 tasks (of 9 key e-waste job categories). Additionally, we categorized four main e-waste activities (in brackets % of population self-reported main activity): dealing (22.4%), sorting (24.1%), dismantling (50%), and burning (3.4%) e-waste materials. Many blood and urinary elements (including essential ones) were within biomonitoring reference ranges. However, blood cadmium (1.2 $\mu\text{g/L}$ median) and lead (6.4 $\mu\text{g/dl}$; 67% above U.S. CDC/NIOSH reference level), and urinary arsenic (38.3 $\mu\text{g/L}$; 39% above U.S. ATSDR value) levels were elevated compared to background populations elsewhere. Workers who burned e-waste tended to have the highest biomarker levels. The findings of this study contribute to a growing body of work at Agbogbloshie (and elsewhere) to document that individuals working within e-waste sites are exposed to a number of toxic elements, some at potentially concerning levels.

Exposure to typical persistent organic pollutants from an electronic waste recycling site in Northern China[☆]



CrossMark

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H I G H L I G H T S

- We measured organohalogen pollutants in human serum from an e-waste site unreported.
- Multivariate regression was applied to explore influencing factors of exposure.
- Elevated exposure to most pollutants was associated with imported e-waste.
- Local residents suffered equal exposure to relatively high volatile pollutants.

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A B S T R A C T

Human exposure to pollutants from e-waste is an important scientific issue for their health effects. In this study, organohalogen pollutants in human serum sample from an e-waste dismantling site ($n = 35$) and a control site ($n = 21$), both located in Tianjin, Northern China, were analyzed using GC–ECNI–MS. Geometric mean concentrations of tetra- through hexa-BDEs, hepta- through nona-BDEs, PCBs, PBB-153, and DP in the exposure group were 2.77, 12.2, 44.1, 0.52, and 7.64 ng g⁻¹ lipid, respectively, which ranged from 1.5 to 7.4-fold higher than those in the control group through multivariate regression analysis, indicating that working and/or living in the e-waste site was associated with elevated body concentrations of these pollutants. Pollutants with low vapor pressures (i.e., hepta- through nona-BDEs and DP) were at significantly higher levels for e-waste dismantling workers than for local residents living around the e-waste site, suggesting higher exposure to these pollutants might exist for the occupational workers.

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Atmospheric polychlorinated biphenyls from an urban site near informal electronic waste recycling area and a suburban site of Chennai city, India



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HIGHLIGHTS

- Several folds higher atmospheric PCBs in urban site over suburban site of Chennai.
- Strong localised sources impacted the emission of atmospheric PCBs in the urban site.
- Lack of significant difference between summer and winter atmospheric PCBs concentrations in the suburban site.
- Emission of dioxin like PCBs due to informal e-waste recycling and open burning in dumpsites.

GRAPHICAL ABSTRACT



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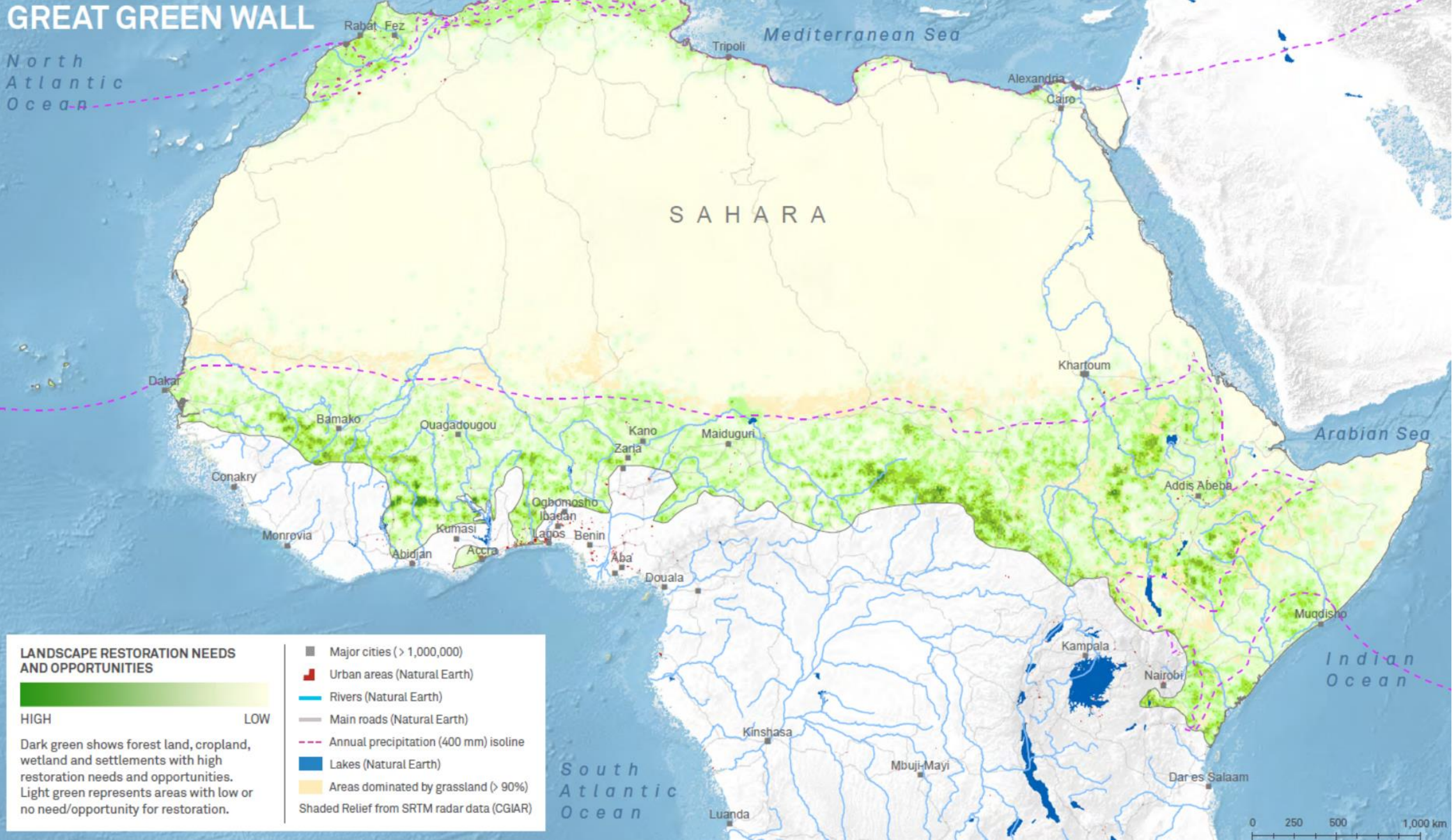
ABSTRACT

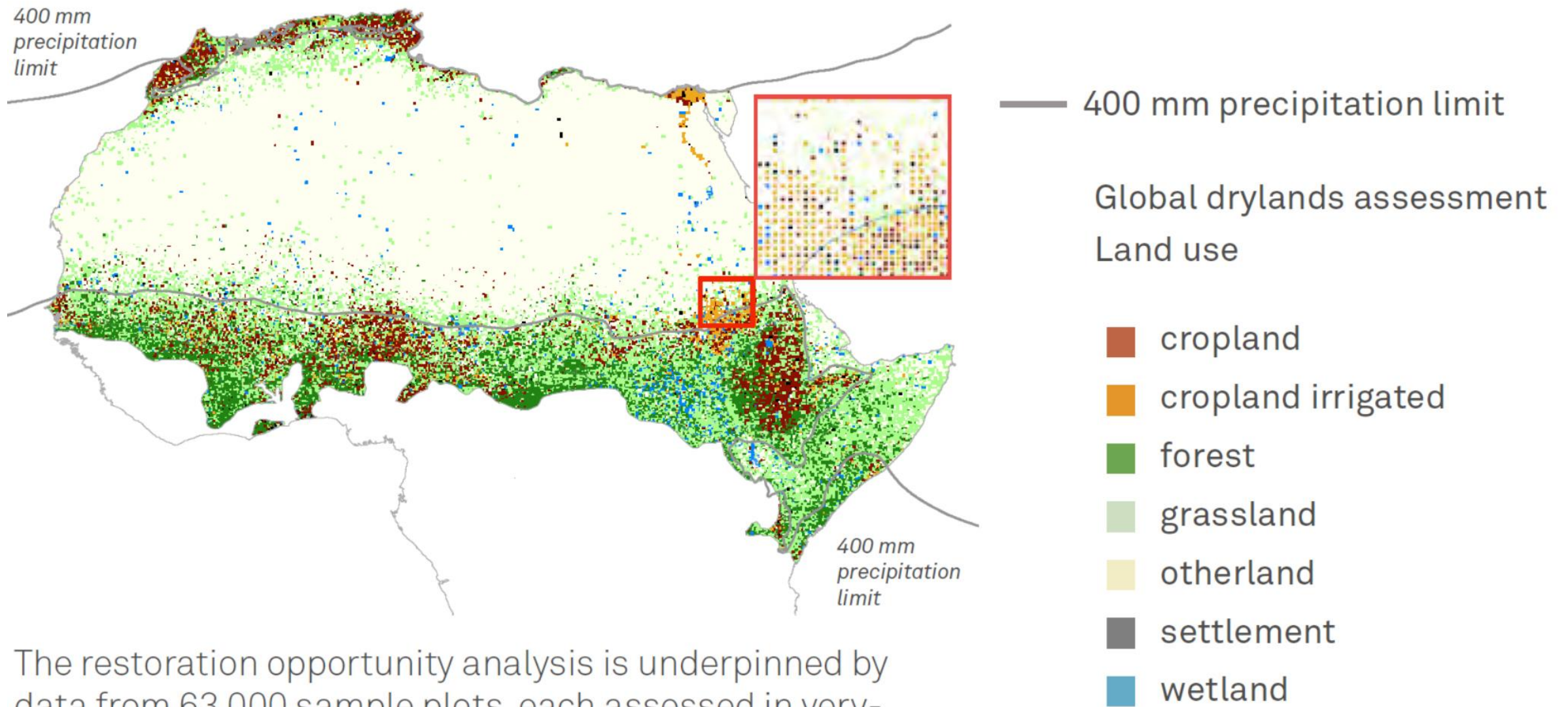
Recent studies evidenced informal electronic waste (e-waste) recycling as a potential source of polychlorinated biphenyls (PCBs) in the metropolitan environment of India. Given the recent evidences on the release of hazardous organic compounds from the informal e-waste recycling workshops in the Chennai city, we have conducted high volume air sampling in an urban site close to the informal e-waste recycling corridor and in a suburban site located about 35 km away from the urban center. Weekly diurnal gaseous and particulate phase samples were collected from both urban and suburban sites during summer and winter samples were collected only from suburban site. Mean atmospheric PCB levels in the urban site ($\text{Avg} \pm \text{Stdev}$, $46 \pm 16 \text{ ng/m}^3$) is several orders of magnitude higher than suburban summer ($10 \pm 12 \text{ ng/m}^3$) and winter ($4 \pm 3 \text{ ng/m}^3$). Back trajectories originating from the land seems to have impacted the samples recorded with maximum PCB concentration. No significant difference was seen between summer and winter atmospheric PCBs in the suburban site. In urban site, PCB-52 and dioxin like PCBs (dl-PCBs) have increased from the past observations with maximum PCB-52 concentration in night time samples. Positive matrix factorization source-receptor model outputs suggest that in the urban centers, open burning in municipal dumpsites is a major source for PCB-52, while dl-PCBs were related to e-waste recycling by the informal sector. Exponential increment in most toxic non-ortho dl-PCBs proclaims the severity of on-going sources which contributed to the high toxic equivalency (TEQs) upto 105 pg TEQ/m^3 .

“Green wall” initiative in Sahel – Sahara region

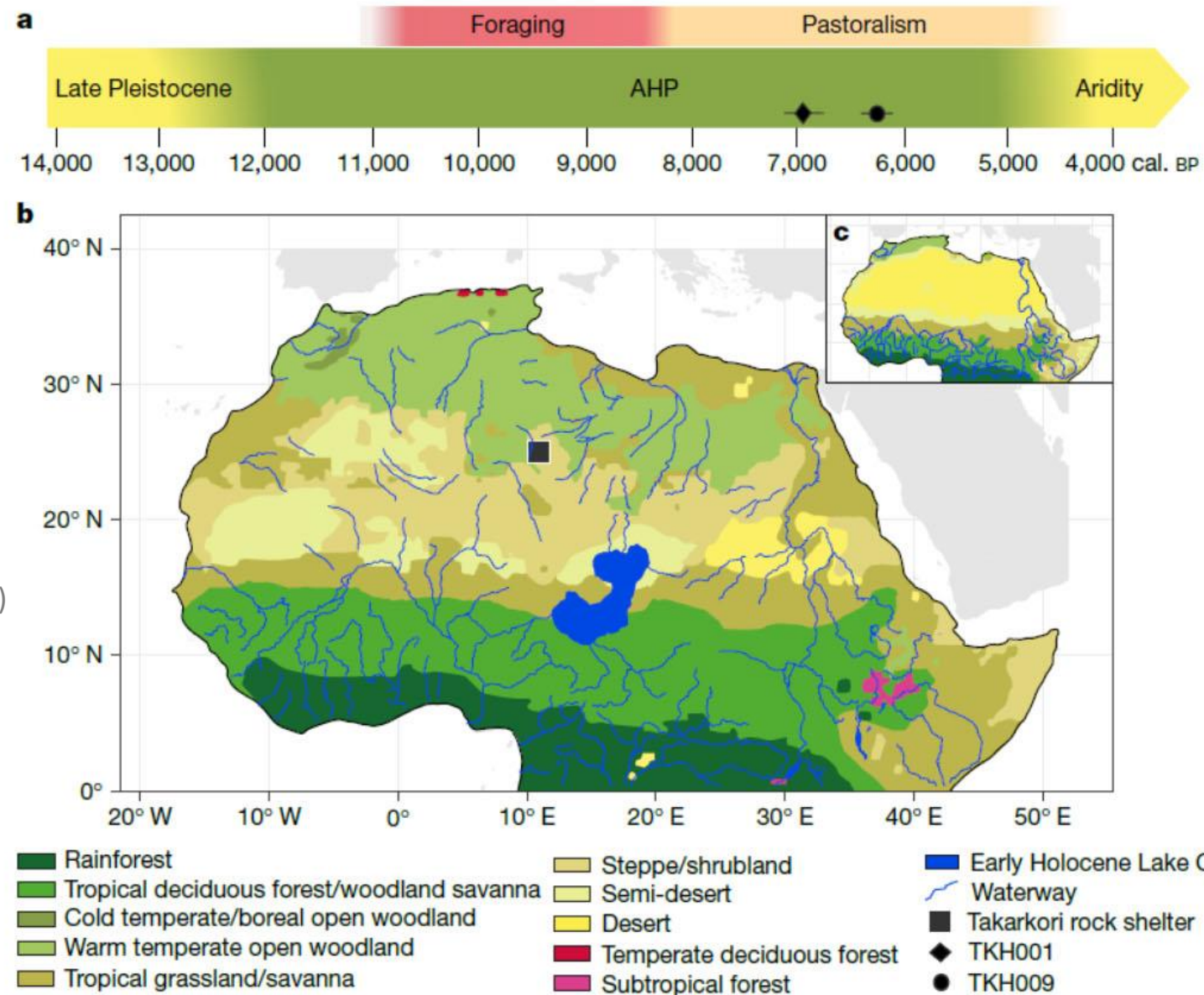
- the region is home to many of the world’s poorest people, who live in some of the driest conditions and are among the most vulnerable to desertification and climate change
- ambitious plan to restore a 7,000-kilometre-long stretch of degraded land from Senegal in West Africa to Djibouti in the east
- up to date, less than **one-fifth of the designated land area has been restored or rehabilitated**; 20 million hectares had been restored, and 350,000 jobs had been created
- there is political instability in the countries of Africa, African Union’s top decision makers don’t see the green wall as a priority, and hence international donors seem reluctant to commit further funding
- besides planting the trees, the initiative has evolved into a more complex set of activities, including improving soils, setting up community gardens/farms and protecting existing forests

GREAT GREEN WALL





The restoration opportunity analysis is underpinned by data from 63 000 sample plots, each assessed in very-high-resolution satellite images by local experts using the Open Foris Collect Earth tool.



Climate in Sahara region was more humid in early Holocene compared to present

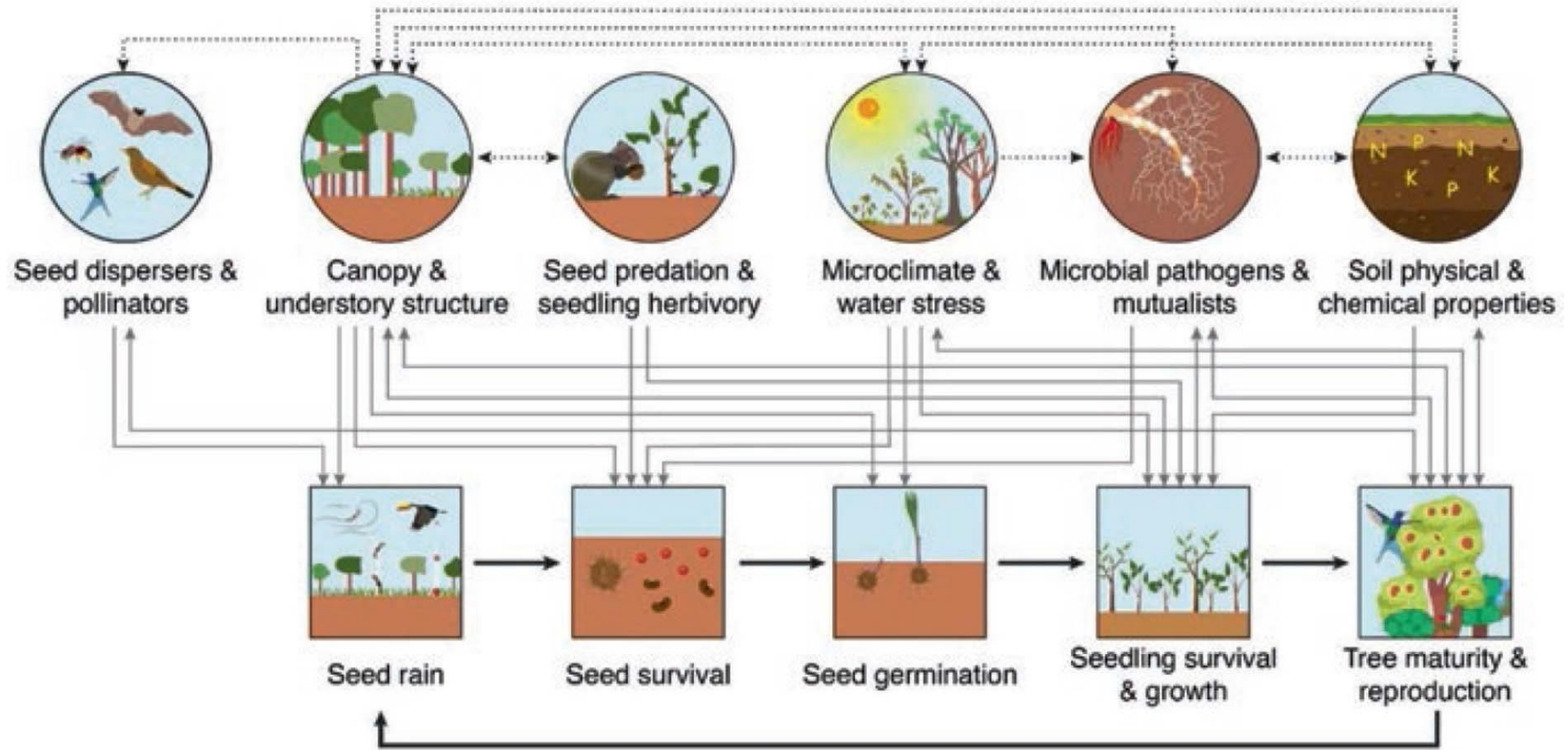
(<https://doi.org/10.1038/s41586-025-08793-7>)

Chronology of the ecozones and subsistence strategies in the broader Sahara region. **a**, Timeline of climate phases and subsistence strategies during the late Pleistocene and the Holocene in North-East Africa and Central Sahara. The radiocarbon dates for both Takarkori individuals are given by the black diamond and circle. **b,c**, The distribution of ecozones in Northern Africa in the

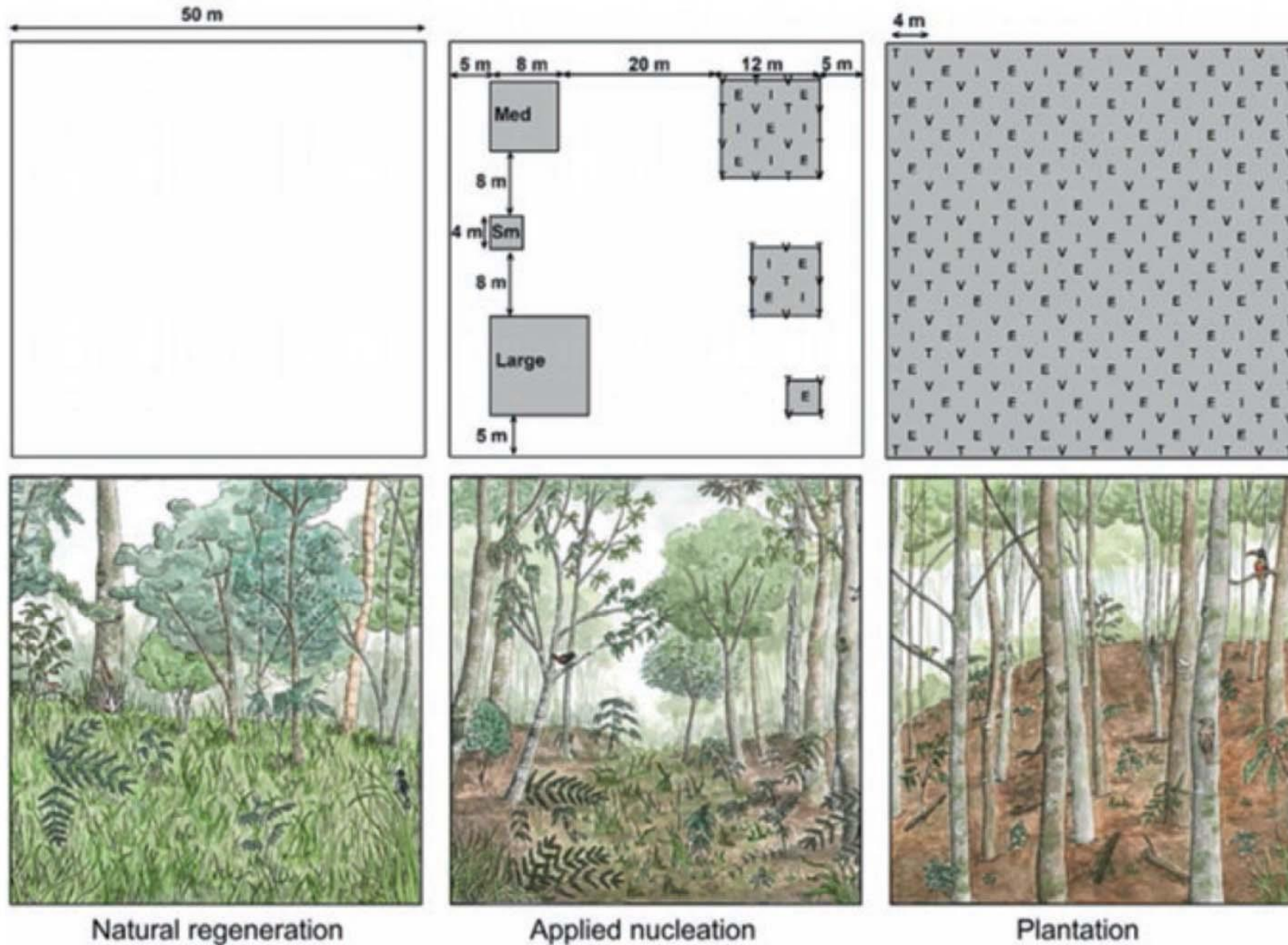
Green Sahara period during the early Holocene 9,000 years ago (**b**) and in recent times (1901–1930) (**c**) using the dynamic vegetation model Carbon Assimilation in the Biosphere (CARAIB). The location of the Takarkori rock shelter site is marked with a black square. The maps are adapted from refs. 20 and 60 under a Creative Commons licence CC BY 4.0.

Planting / Establishing a forest (factors to consider)

- planting the trees with lower demands for water and soil status (in semiarid climate), especially during initial stage of succession
- employment of local people to stop the fires and help guard the land
- planting enough species to start attracting pollinators and seed dispersers; the key is getting the canopy to close quickly enough — by the second or third year — to prevent weeds from taking over
- there is no “one-size-fits-all” solution, it’s about matching trees to their location; for example, it is a good idea to plant (exotic) fruit-bearing trees that benefit not only local people but animals as well, which may help to spread the seeds
- example: fig trees (*Ficus* spp.) grow well in tropical forests around the world and produce regular fruit crops that birds, bats and primates rely on — particularly during dry periods — and their foliage is an important food source for other animals
- strategy, known as applied nucleation, involves planting small clusters, or ‘nuclei’, of trees throughout the parcel. The goal is for these to gradually close in on each other, as the nuclei attract seed dispersers. It can be just as effective as planting a whole area with trees, but it requires fewer resources, and the outcome is a more varied-looking landscape.



Ecological factors affecting the rate of forest recovery. Square boxes illustrate stages in the dispersal, establishment and reproduction of vegetation. Circles illustrate ecological factors that affect the rate of transitions between the stages.
 source: Singarayer et al., 2023. Ecological Restoration.



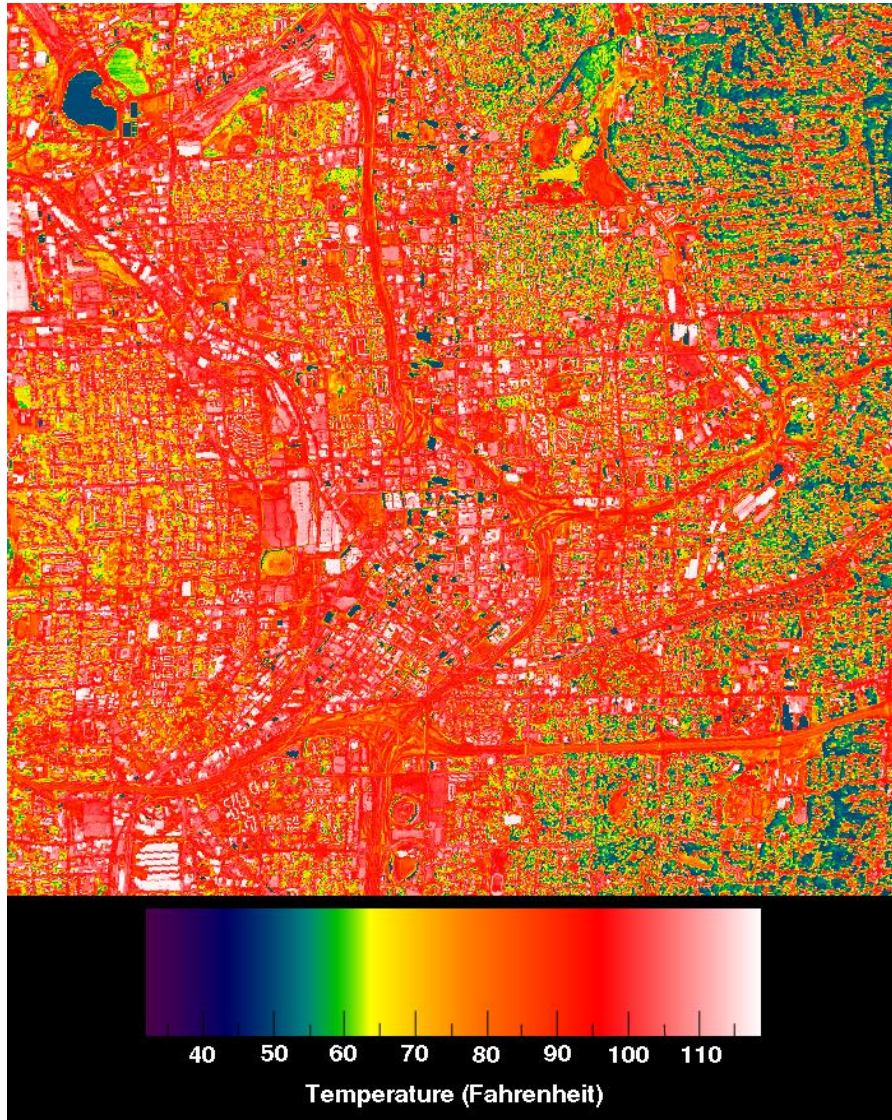
Top panels show planting design and bottom panels illustrate the plots after 15 years, showing both planted and naturally recruited vegetation. In top panels, grey areas were planted with *E* *Erythrina poeppigiana*, *I* *Inga edulis*, *T* *Terminalia amazonia* and *V* *Vochysia guatemalensis*. Sm small, Med medium; source: Singarayer et al., 2023. Ecological Restoration.

Land degradation in intensively urbanized areas (soil sealing)

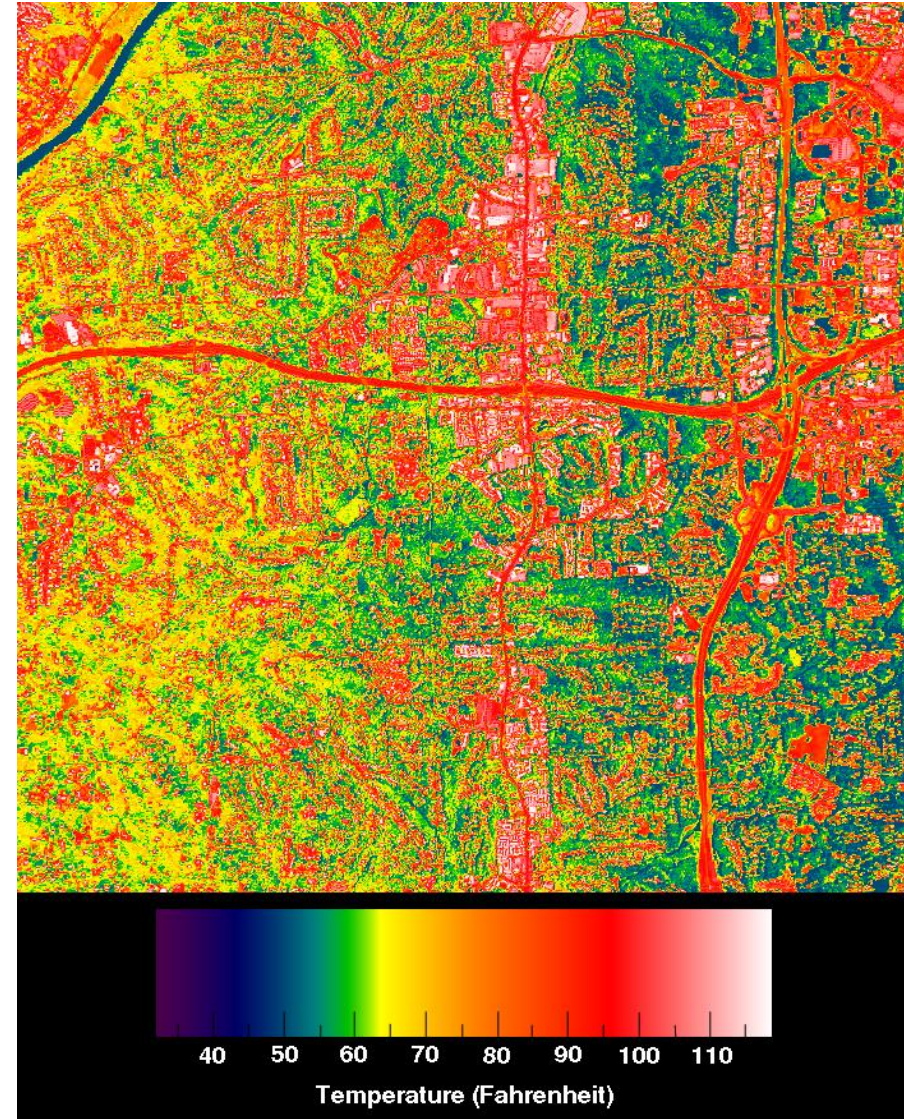
- 0.43 % of terrestrial land is covered by impermeable surfaces (global); 9 % in Europe; although the extent of urbanized area is not that big, there are some consequences that lower the environmental quality of urbanized landscape in certain cases
- the consequences are associated with 1. thermal and 2. hydrological processes
- 1. urban heat island: buildings, roads, and other infrastructure absorb and re-emit the sun's heat more than forests, grasslands and/or water bodies; why? because soil-plant-water system is missing; precipitation water enters the soil, part of the water percolates deeper and remaining part is gradually released into the atmosphere either through evapotranspiration, this process is endothermic – it “consumes” the heat → it cools the surroundings
- 2. large portion of impermeable surface causes increased surface runoff, decrease of evapotranspiration; this may alter (and decrease) recharge rates of the water reservoirs in the subsurface

Urban heat island: Atlanta (USA)

city center/downtown

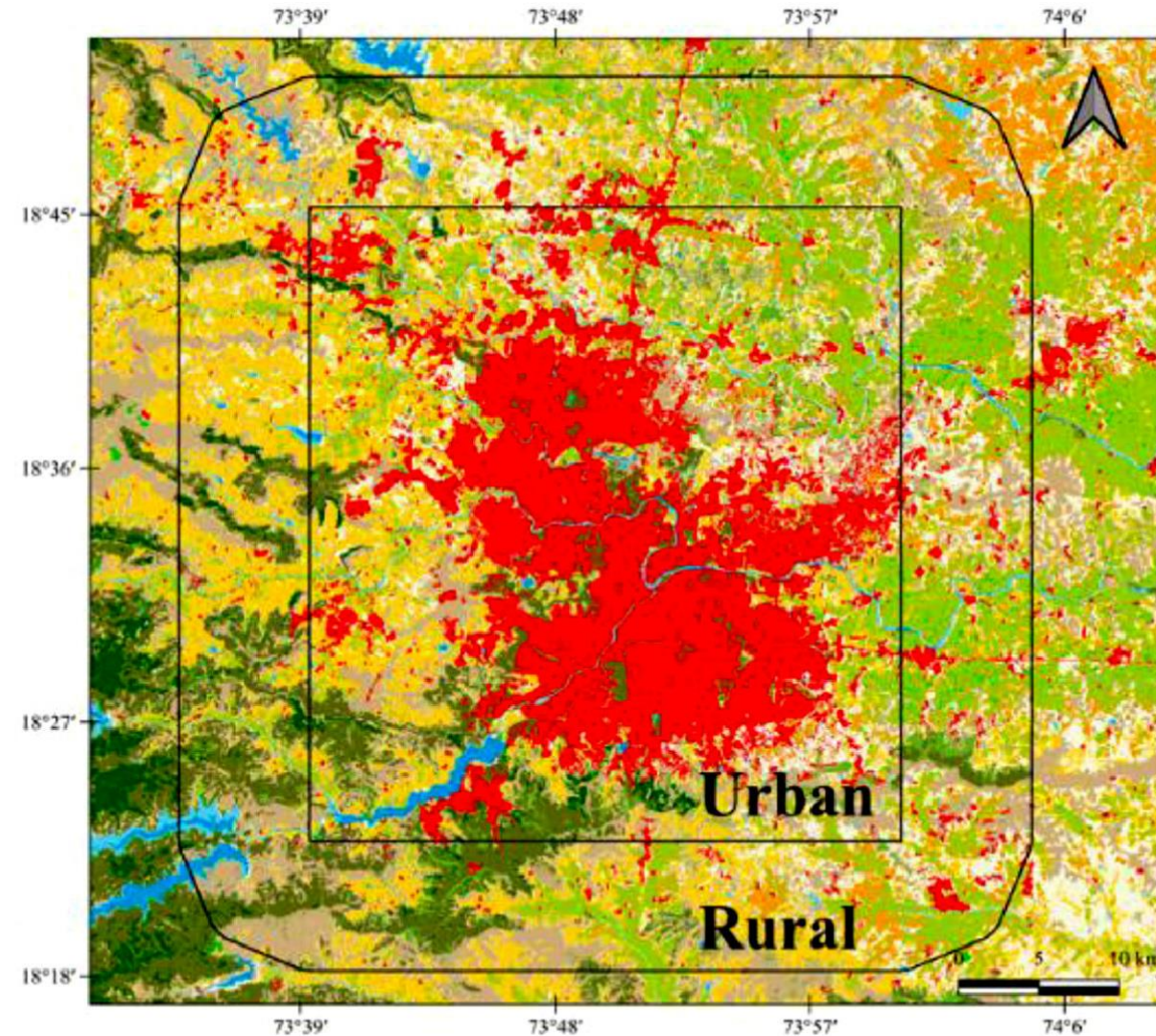
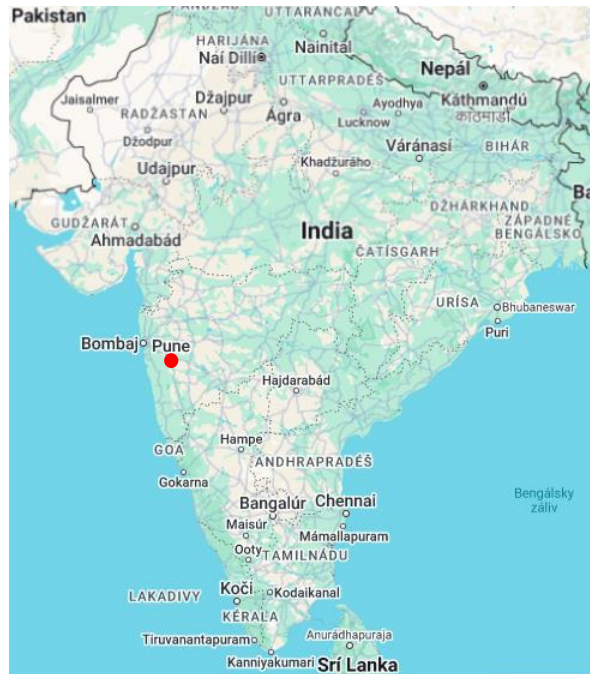


suburb/countryside



Pune, India

number of residents: 5 064 700 (2008)

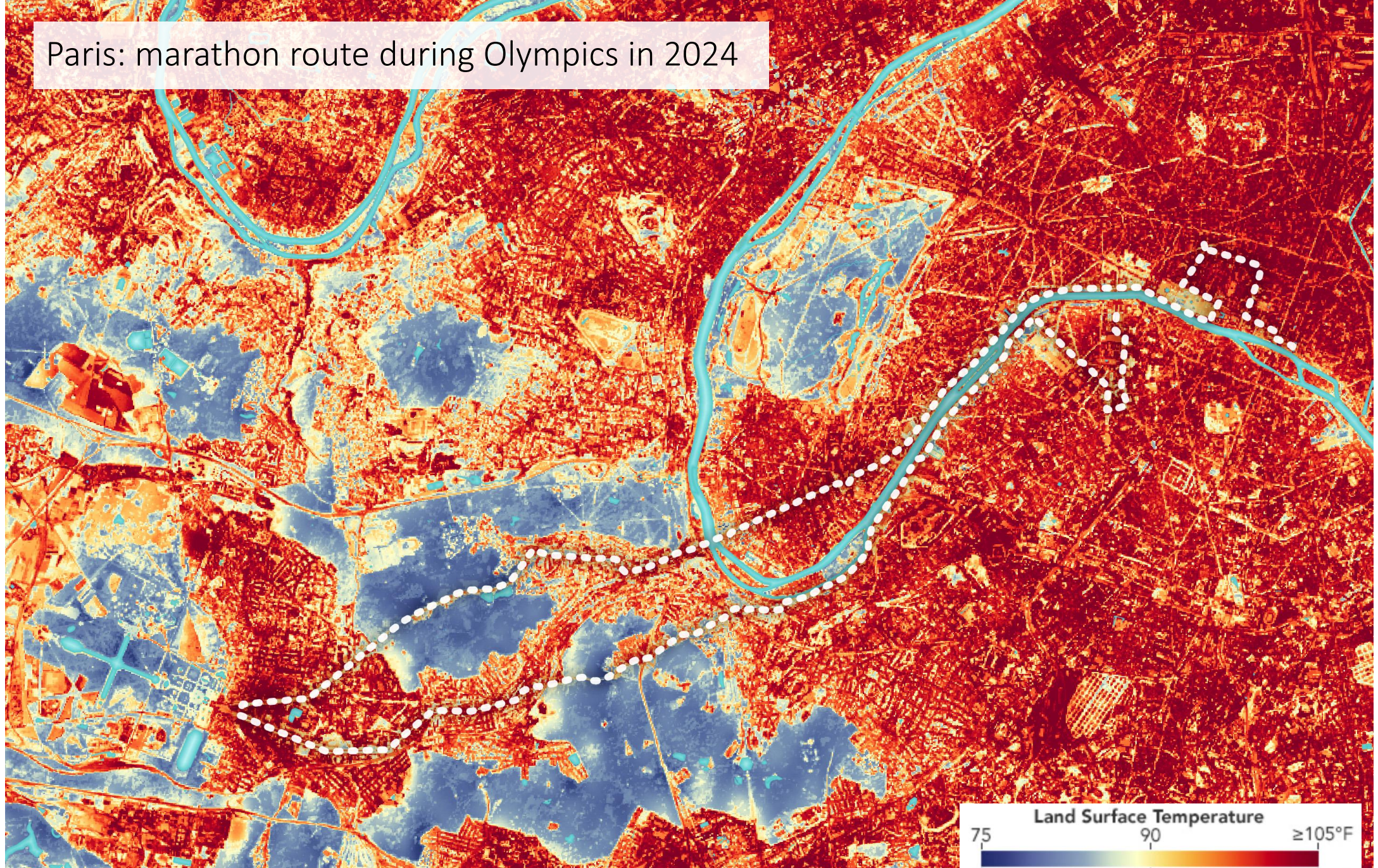


Urban and Rural Boundaries, Pune

Paris: marathon route during Olympics in 2024



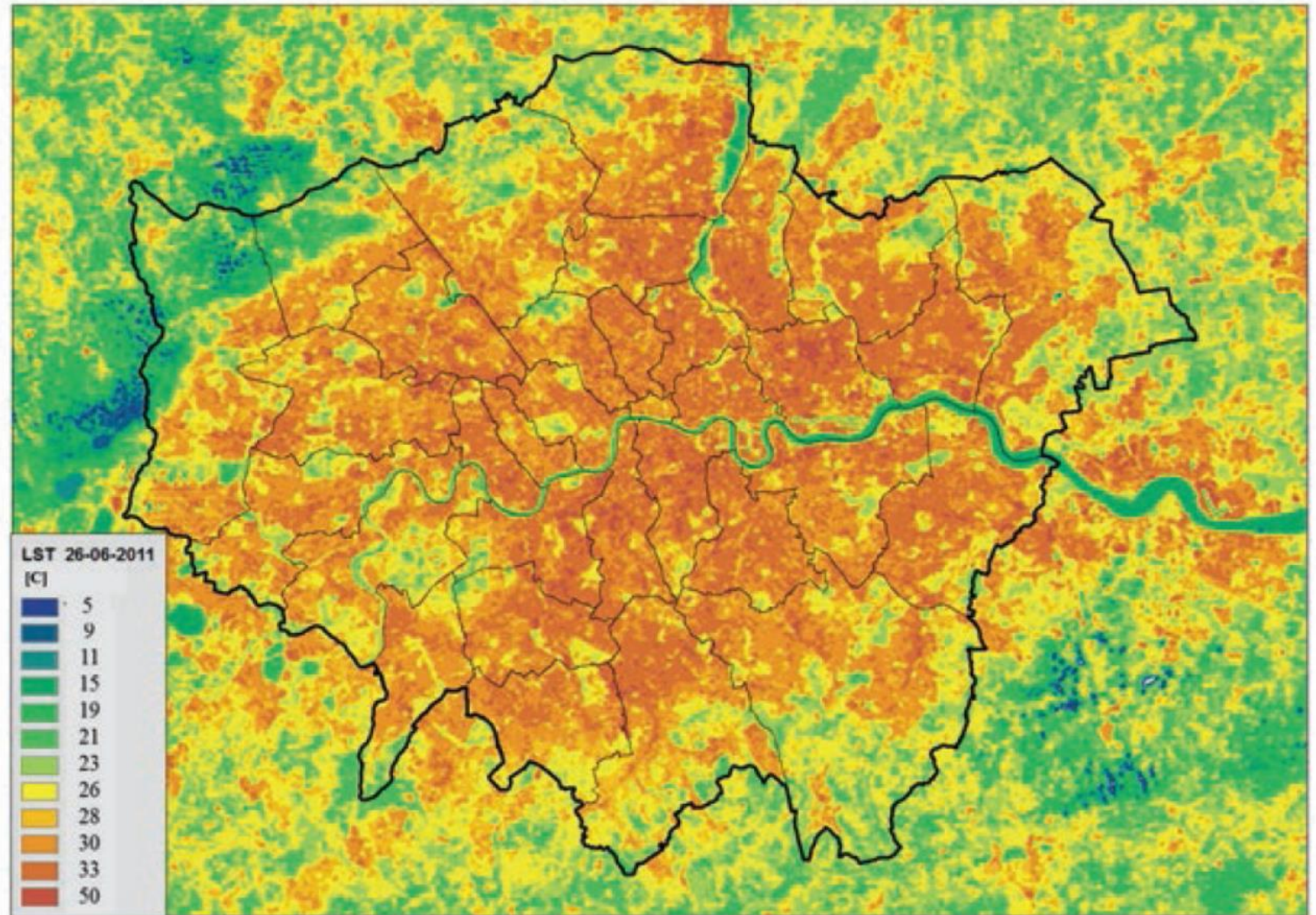
Paris: marathon route during Olympics in 2024



<https://earthobservatory.nasa.gov/images/153178/running-through-paris-heat>

Urban heat island: London

26.6. 2011



Soil sealing (effect on water balance – Leipzig, Germany)

- 587 857 inhabitants (2019)
annual rainfall $\approx$ 570 mm (roughly similar to Bratislava)

surface runoff:

- 25 to 150 mm/year on surfaces minimally affected by urbanization
- the amount of surface runoff doubled $\rightarrow$ 50 to 300 mm/year in areas with 20 to 40% soil sealing degree
- 225 to 350 mm/year runoff was measured in the areas with 40 to 60% soil sealing degree
- runoff $>$ 325 mm/year was measured in the areas with $>$ 80% soil sealing degree $\rightarrow$ that is roughly 75% of the annual rainfall $\approx$ 450 mm/year

source: D. Haase / Environmental Impact Assessment Review 29 (2009) 211–219.

Soil sealing (effect on water balance – Leipzig, Germany)

evapotranspiration

- The increase in surface runoff led to a decrease in evapotranspiration rate
- evapotranspiration decreased by 100 až 150 mm/year in the areas with 20 až 40 % soil sealing degree
- evapotranspiration decreased by 450 mm/year in the areas with 80 % soil sealing degree

groundwater recharge

- groundwater recharge rate under agricultural areas ranges approximately from 125 to 175 mm per year
- urbanization caused decrease in recharge rate by 25 – 150 mm, depending on the degree of coverage with impermeable surfaces

zdroj: D. Haase / Environmental Impact Assessment Review 29 (2009) 211–219.

