Earth Observation for Public Health

Topical Overview

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Glossary of acronyms

AD	Administrative District
ADB	Asian Development Bank
AI4EO	Artificial Intelligence for Earth Observation portal
CAREC	Central Asian Regional Economic Cooperation
CAMS	Copernicus Atmosphere Monitoring Service
CoP	Community of Practice
COVID-19	Coronavirus disease of 2019
D-MOSS	Dengue forecasting MOdel Satellite-based System
DTE	Digital Twin Earths
ECMWF	European Centre for Medium-Range Weather Forecasts
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EO	Earth Observation
eo4society	EO science for society
EEAA	Egyptian Environmental Affairs Agency
ESA	European Space Agency
FCDO	UK Foreign, Commonwealth & Development Office
FMI	Finnish Meteorological Institute
GDA	Global Development Assistance
GDA AID	GDA Agile Earth Observation Information Development
GDA APP	GDA Analytics Processing Platform
GDA CCC	GDA Impact Communication
GDA ITT	GDA Invitation To Tender
GDP	Gross Domestic Product
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GFCS	Global Framework for Climate Services
GHSL	Global Human Settlement Layer

GIDEON	Global Infectious Diseases and Epidemiology Network
GIS	Geographic Information Systems
GRID3	Geo-Referenced Infrastructure and Demographic Data for Development
HHV	Heat-Health Vulnerability
HIC	High-income country
HNP	Health, Nutrition and Population
IDA	International Development Association
IFI	International Financial Institution
IPP	International Partnership Programme
IRS	Indoor Residual Spraying
ITN	Insecticide-Treated Nets
JAXA	Japan Aerospace Exploration Agency
JRC	Joint Research Centre
Lao PDR	Lao People's Democratic Republic
LIC	Low-income country
LMIC	Low- and middle-income country
MDTF	Multi-Donor Trust Fund
MEA	Multi-sensor Evolution Analysis
ML	Machine Learning
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NCD	Non-Communicable Disease
NDBI	Normalised Difference Built-up Index
NDT	Neglected Tropical Disease
NIVR	Netherlands' Agency for Aerospace Programs
NMCP	National Malaria Control Programme
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides

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NTL	Nighttime Lights
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
OMI	Ozone Monitoring Instrument
$PM_{2.5}$	Fine Particulate Matter
PM_{10}	Coarse Particulate Matter
PMEH	Pollution Management and Environmental Health Program
PPR	Prevention, Preparedness, and Response
R&D	Research & Development
RACE	Rapid Action for Citizens with Earth Observation
RAMP	Replicable AI for Microplanning
REDISSE	Regional Disease and Surveillance Systems Enhancement
RESAP	Regional Space Applications Programme
SOW	Scope of Work
SPAR	Stunting Prevention and Reduction Programme
TA	Technical Assistance
UHC	Universal Health Coverage
US	United States
UN	United Nations
UN SDG	United Nations Sustainable Development Goal
UNDP	United Nations Development Programme
UNESCAP	United Nations Economic and Social Commissions for Asia and the Pacific
UNICEF	United Nations Children's Fund
UNOOSA	United Nations Office for Outer Space Affairs
UNFP	United Nations Population Fund
WB	World Bank
WHO	World Health Organisation
WMO	World Meteorological Organisation

Key points

Public health faces significant challenges, including macroeconomic budgetary constraints, socio-demographic trends, and climate-related issues, all of which have direct and indirect implications for global health.

These trends have worsened during the recent COVID-19 pandemic, placing even greater pressure on health systems worldwide, resulting in thousands of additional deaths and tens of millions of people suffering longer-term health implications from the illness.

The World Bank (WB) and the Asian Development Bank (ADB) work with governments in low- and middle-income countries (LMICs) to address public health challenges in distinct ways:

- The WB has identified four focus areas within public health: strengthening health systems and pandemic preparedness; health financing; climate change and health; and nutrition.[1]
- The ADB bases its health sector directional guide on key trends affecting public health outcomes in the region: rapid urbanisation and climate change; demographic shifts; decentralisation and regional cooperation; digitalisation of health processes; and threats due to the pandemic.[2]

Earth Observation (EO) has the potential to contribute towards four key public health challenges:

- Strengthening health systems and the delivery of health services
- Controlling disease outbreaks through environmental monitoring
- Managing extreme weather events
- Understanding air quality and its implications for health

This report has not identified many examples of EO being used for public health in the WB or the ADB, despite the potential benefits it could bring to the WB's focus areas and the ADB's ability to address the key trends driving public health challenges.

The European Space Agency (ESA) has seen an increase in research and pre-operational demonstration activities aimed at integrating EO data into global public health efforts both internally and through partnerships with other institutions and space agencies. There has also been an increasing focus on the nexus between climate resilience and health.

Under the new Global Development Assistance (GDA) Agile Earth Observation Information Development (AID) for Health activity, ESA will support the operationalisation and mainstreaming of EO products in global health programmes, in collaboration with International Financial Institution (IFI) partners such as the WB, ADB, and others.[3]

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[1] WB, 'Health Overview: Focus Areas', 2023, https://www.worldbank.org/en/topic/health/overview#3
[2] ADB, 'Strategy 2030: Achieving a Prosperous, Inclusive, Resilient, and Sustainable Asia and the Pacific,' 2018, https://www.adb.org/documents/strategy-2030-prosperous-inclusive-resilient-sustainable-asia-pacific
[3] ESA, 'New ITT released for GDA AID Public Health', 2023, https://gda.esa.int/2023/10/new-itt-released-for-gda-aid-public-health/

Introduction

Global public health is a transdisciplinary field of research and action where policymakers, health practitioners, scientists, and development actors come together to solve a range of different challenges. Health is an important foundational requirement that can dictate the smooth functioning of any economy and an important enabler of broader progress in sustainable development. United Nations Sustainable Development Goal (UN SDG) 3 commits to "*ensure healthy lives and promote well-being for all at all ages.*"[4] SDG 3 is invariably linked to other SDGs (see Figure 1).

Figure 1: SDG 3 and Health-Related Linkages with Other SDGs[5]

[4] UN, 'Transforming our world: The 2030 Agenda for Sustainable Development,' 2015, https://sdgs.un.org/goals
[5] WHO, 'Monitoring the Health-Related Sustainable Development Goals (SDGs),' 2017, https://cdn.who.int/media/docs/default-source/searo/hsd/hwf/01-monitoring-the-health-related-sdgs-background-paper.pdf?sfvrsn=3417607a_4&download=true

EO imagery has the potential to improve global public health and directly contribute to the monitoring and achievement of SDG 3 and other related SDGs. For instance, EO data is used to predict natural disasters and can strengthen resilience to climate-related hazards (SDG target 13.1), which in turn could prevent injury and loss of life, improve public health, and contribute to SDG 3.

This report does not cover the value of EO data in disaster resilience, water and sanitation, or nutrition, all of which can impact health. Instead, it focuses on how EO directly contributes to public health by tackling four challenges faced by countries worldwide. These challenges have been defined based on a combination of the WB's and ADB's health focus areas, as well as case studies and academic references that best demonstrate the value that EO brings to public health:

- Strengthening health systems and the delivery of health services
- Controlling disease outbreaks through environmental monitoring
- Managing extreme weather events
- Understanding air quality and implications for health

The report is structured as follows.

- **Background**: An overview of public health and the key challenges IFIs will face in improving public health for all.
- **Public health in IFIs**: An overview of how the WB and the ADB tackle public health.
- **The value of EO for public health**: An analysis of EO's main contributions to public health.
- **Case studies**: A list of all case studies to address global health challenge areas.
- **Current use of EO for public health in the WB and the ADB**: An overview of how the WB and ADB use EO for public health.
- **Ongoing activities relating to EO and public health**
- **Potential limitations/barriers to the increased adoption of EO for public health**

Background

The state of global public health

Public health is *"the science and art of preventing disease, prolonging life, and promoting health through the organized efforts and informed choices of society, organizations, public and private communities, and individuals".*[6]

The World Health Organisation's (WHO) overall objective is to achieve universal health coverage (UHC), in which *"all people have access to the full range of quality health services they need, when and where they need them, without financial hardship".*[7] This covers all essential health services, from prevention to treatment to rehabilitation. Worldwide, progress towards UHC is off-track. Health service coverage levels have stagnated since 2015, and an estimated one billion people are experiencing catastrophic out-of-pocket health spending, with a third of them going deeper into extreme poverty due to health-related costs.

Low-income countries (LICs) spend only 4.9% of their Gross Domestic Product (GDP) on health, compared to high-income countries (HICs) which spend 12.5% of their GDP on health.[8] During the pandemic, the limited funds spent on health diverted towards the coronavirus disease in 2019 (COVID-19), resulting in the disruption of essential services and over 22 million children missing vaccinations.[9] With the growing burden of non-communicable diseases (NCDs), many countries were already struggling to close the gap between the demand for health spending and available public funds. However, the COVID-19 pandemic has further disrupted the regular care often required by patients with NCDs, with 75% of countries reporting interruptions to NCD services in 2020.[10] NCDs (e.g., heart disease, stroke, cancer, diabetes, chronic lung disease) are now collectively responsible for 74% of all deaths worldwide, with three-quarters of these deaths occurring in LMICs.[11]

Another important trend in global public health is the effect of climate change on the natural environment and, subsequently, on human behaviours, habits, and lifestyles. The WHO identifies climate change as humanity's biggest health threat.[12] Climate change impacts the emergence, re-emergence, and spread of infectious diseases by causing a shift in the geographic range of important vector species and the diseases they transmit. At the same time, environmental degradation, including desertification and deforestation, is driving populations from rural to urban areas, leading to the growth of urban environments and the spread of urban settlements into wildlife habitats. Unplanned or precarious urbanisation allows invasive vectors and novel pathogens to spread widely and increases the risk of zoonotic diseases transferring from animals to humans.

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[6] C. E. Winslow, 'The Untilled Fields of Public Health,' Science 9, no. 51 (1920): 23–33, https://pubmed.ncbi.nlm.nih.gov/17838891/
[7] WHO, 'Universal health coverage,' 2023, https://www.who.int/health-topics/universal-health-coverage#tab=tab_1
[8] WB, 'Current health expenditure (% of GDP),' 2022, https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS
[9] WHO, 'COVID-19 pandemic leads to major backsliding on childhood vaccinations, new WHO, UNICEF data shows,' 2021, https://www.who.int/news/item/15-07-2021-covid-19-pandemic-leads-to-major-backsliding-on-childhood-vaccinations-new-who-unicef-data-shows
[10] A. Clark et al., 'Global, regional, and national estimates of the population at increased risk of severe COVID-19 due to underlying health conditions in 2020: a modelling study,' Lancet Global Health 8, no. 8 (2020): e1003–e1017, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7295519/
[11] WHO, 'Noncommunicable diseases: Mortality,' 2021, https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/ncd-mortality
[12] WHO, 'Climate change and health,' 2021, https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

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The risk of potential pandemics was increasing even before COVID-19, and the global health system remains vulnerable to further setbacks and strains from these shocks.

Urbanisation and increased industrialisation also influence air quality and levels of pollution. According to the Organisation for Economic Co-operation and Development (OECD), air pollution has overtaken poor sanitation and a lack of clean drinking water as the main environmental cause of premature death.[13] Worsening air quality is associated with pollutants, which impact agricultural productivity, natural ecosystems, and human health and welfare. The WB estimates that the global cost of health damages associated with exposure to air pollution is US$8.1 trillion, equivalent to 6.1% of the global GDP.[14] Moreover, 99% of people worldwide are exposed to air that fails to meet WHO air quality guideline standards, with LMICs suffering from the highest exposures.[15]

As the climate is changing, extreme weather events are becoming increasingly likely, frequent, long, and damaging. The world is seeing ever-higher temperatures and experiencing extreme drought, flooding events, and intense storms. In 2015 alone, 175 million more people were exposed to heatwaves compared to the yearly average.[16] Exposure to excessive heat can amplify existing health conditions, including respiratory and cerebrovascular diseases, and result in disability and premature death. Long periods of hot and dry weather can also increase the risk of wildfires, which not only directly injure or kill people, but also form secondary pollutants such as ozone (O_3), which worsen air quality and in turn cause respiratory diseases.

[13] OECD, 'The Cost of Air Pollution,' 2014, https://www.oecd-ilibrary.org/environment/the-cost-of-air-pollution_9789264210448-en
[14] Open Knowledge Repository (OKR), 'The Global Health Cost of $PM_{2.5}$ Air Pollution: A Case for Action Beyond 2021,' 2022, https://openknowledge.worldbank.org/entities/publication/c96ee144-4a4b-5164-ad79-74c051179eee
[15] WHO, 'Air Pollution,' 2023, https://www.who.int/health-topics/air-pollution#tab=tab_1
[16] WHO, 'Heat and Health,' 2018, https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health#:~:text=Rapid%20rises%20in%20heat%20gain,exhaustion%2C%20heatstroke%2C%20and%20hyperthermia.

Public health in International Financial Institutions (IFIs)

The World Bank (WB)

The International Development Association (IDA), the WB's fund for those most in need, financed essential health interventions for almost 880 million people over the last decade.[17] The WB has a global strategy for health, nutrition, and population, and a global health portfolio of US$34 billion across 240 projects.

The WB supports efforts to achieve UHC by strengthening primary health systems and providing high-quality and affordable services to everyone—especially the most vulnerable. In its pursuit of UHC, the WB has identified four focus areas: strengthening health systems and pandemic preparedness; health financing; climate change and health; and nutrition.

Strengthening health systems and pandemic preparedness

Pandemics not only threaten countries' ability to achieve UHC but also pose a risk to their economic security. Strong health systems enable countries to better prevent a disease outbreak from becoming a pandemic. The WB helps LMICs achieve UHC by building stronger health systems and providing quality, affordable health services to all. The WB has mounted the largest crisis response in its history to help LMICs strengthen their response to COVID-19, committing over US$200 billion from April 2020 to March 2021 to public and private sector clients fighting the impacts of the pandemic.[18] Additionally, in September 2022, the new Pandemic Fund, housed at the WB, was officially established to strengthen pandemic Prevention, Preparedness, and Response (PPR) capabilities in LMICs, addressing key gaps through technical support and investment.

Health financing

Global economic shocks related to both the COVID-19 pandemic and the Russian invasion of Ukraine have affected the spending capacity of governments across the world, leading to a stagnation or decline in public investment in critical infrastructure, including health. The WB supports LMICs to resolve debt challenges caused by the rise in global interest rates and to manage public finances so that funds for health are well spent and revenues can be raised from health-damaging products such as alcohol, tobacco, and sugar to meet long-term sector spending needs.

Climate and health

Climate change can exacerbate disease outbreaks, extreme weather events, and conflicts, causing detrimental impacts on both physical and mental health. According to the WB, *"an additional 132 million people could be living in extreme poverty by 2030 due to climate change"*.[19] The most vulnerable groups are particularly affected, including people living in poverty, those with pre-existing health conditions, the elderly, and other marginalised groups.

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[17] WB, 'Health,' 2023, https://www.worldbank.org/en/topic/health/overview
[18] WB, 'How the World Bank Group is helping countries address COVID-19 (coronavirus),' 2022, https://www.worldbank.org/en/news/factsheet/2020/02/11/how-the-world-bank-group-is-helping-countries-with-covid-19-coronavirus
[19] WB, 'Health,' 2023, https://www.worldbank.org/en/topic/health/overview#3

The WB is the largest financier of the fight against climate change in LMICs, including health-related climate activities. The WB's Climate and Health Vulnerability Assessments help countries identify health risks and priorities related to climate change, ensuring that adaptation measures are tailored to their context.

Nutrition

"An estimated 149 million children under 5 are stunted (low height for age)."[20] Stunting not only impacts a child's health but also their brain development, affecting a country's human capital in the long term. Nutrition interventions are consistently identified as one of the most cost-effective development interventions. Tackling malnutrition (both undernutrition and obesity) is a high priority in LMICs. Since 2010, the WB's investments in nutrition have increased dramatically, from US$10 million to about US$1.2 billion in 2018, and it has been a key contributor to the dialogue and action on preventing stunting.[21] The WB is committed to supporting countries with their nutrition by providing technical assistance for nutrition policies and programmes, building the knowledge base around nutrition, and financing evidence-based nutrition interventions.

The Asian Development Bank (ADB)

The ADB works across Asia to improve healthcare provision, aiming to reduce poverty and enhance human capital. It collaborates with various governments to pursue UHC, "*which involves [the] prevention and containment of both communicable and non-communicable diseases*".[22]

The ADB's Strategy 2030 Health Sector Directional Guide identifies key trends affecting public health outcomes in the region: rapid urbanisation and climate change; demographic shifts; decentralisation and regional cooperation; digitalisation of health processes; and threats due to the pandemic.[23]

Rapid urbanisation and climate change

More than 50% of Asia and the Pacific lived in cities in 2019. This number is expected to increase dramatically in the future, leading to greater health risks related to urban living, including exposure to pollution, pathogens, and injury. Urban transport, congestion, and toxic/hazardous waste can make the air quality in urban environments damaging to human health. Crowded conditions, poor sanitation, and inadequate water supplies can increase ill health and disease. Traffic accidents, poorly built infrastructure and housing, and informal settlements can also lead to injuries.

The ADB implements specific actions to address climate change and health, including:

- Supporting Developing Member Countries (DMCs) in preparing climate resilient sector roadmaps.
- Helping DMCs guide adaptation interventions that address health impacts and cost-effective responses.
- Supporting knowledge generation and dissemination on evidence-based good practices on climate change and health.

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[20] WB, 'Health,' 2023, https://www.worldbank.org/en/topic/health/overview#3
[21] WB, 'The World Bank and Nutrition,' 2022, https://www.worldbank.org/en/topic/nutrition/overview#2
[22] ADB, 'ADB's Work in Health,' 2023, https://www.adb.org/what-we-do/topics/health/overview
[23] ADB, Strategy 2030: Achieving a Prosperous, Inclusive, Resilient, and Sustainable Asia and the Pacific, 2018, https://www.adb.org/documents/strategy-2030-prosperous-inclusive-resilient-sustainable-asia-pacific

- Developing operational guidelines for health adaptation options.
- Working in partnership to complement ADB's own capacities on climate change analyses and responses to health impacts.[24]

Demographic shifts

Asia and the Pacific are experiencing longer life expectancies and decreased fertility rates. These demographic shifts are changing the dynamics of health spending, both in terms of the level of public spending that can be budgeted for and the level of care that might be required by the population. By 2050, a quarter of people in Asia and the Pacific will be over 60 years old,[25] causing pressures on healthcare spending and the provision of healthcare services.

To tackle this challenge, the ADB is helping build a knowledge base and network to disseminate expertise in Asia and the Pacific in the development of elderly care systems. The ADB also supports capacity-building initiatives in countries on the strategic planning of elderly care, ensuring that the poor and vulnerable are not left behind.

Decentralisation and regional cooperation

Before the COVID-19 pandemic, LMICs in Asia and the Pacific were increasingly adopting decentralised political and fiscal models, affecting how health-related decisions were being made, financed, and held to account. These trends are likely to return after the pandemic, which will mean there will be an increased need for information sharing within and across LMICs, as well as an increased desire for accountability among citizens.

The ADB aims to enhance regional collaboration by: *"Engaging subnational policymakers to counter limited central capacity; Enhancing regional health cooperation; Increasing information sharing within and across developing member countries"*.[26]

Digitalisation of health processes

In Asia and the Pacific, health and related services can increasingly be promoted, searched for, delivered, financed, and monitored using digital platforms. The widespread use of electronic health and medical records is resulting in greater volumes of data being available to healthcare professionals and policymakers, which has the potential to improve the planning and delivery of services. There is also an increasing need for integrated information services that allow patients to better track their health outcomes. The ADB provides financing and technical assistance to its member countries to improve health information systems.

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[24] ADB, 'Accounting for Health Impacts of Climate Change,' 2011, https://www.adb.org/sites/default/files/publication/28976/heath-impacts-climate-change.pdf
[25] ADB, 'Adapting to Aging Asia and the Pacific,' 2023, https://www.adb.org/what-we-do/topics/social-development/aging-asia
[26] ADB, 'Strategy 2030: Achieving a Prosperous, Inclusive, Resilient, and Sustainable Asia and the Pacific,' 2018, https://www.adb.org/documents/strategy-2030-prosperous-inclusive-resilient-sustainable-asia-pacific

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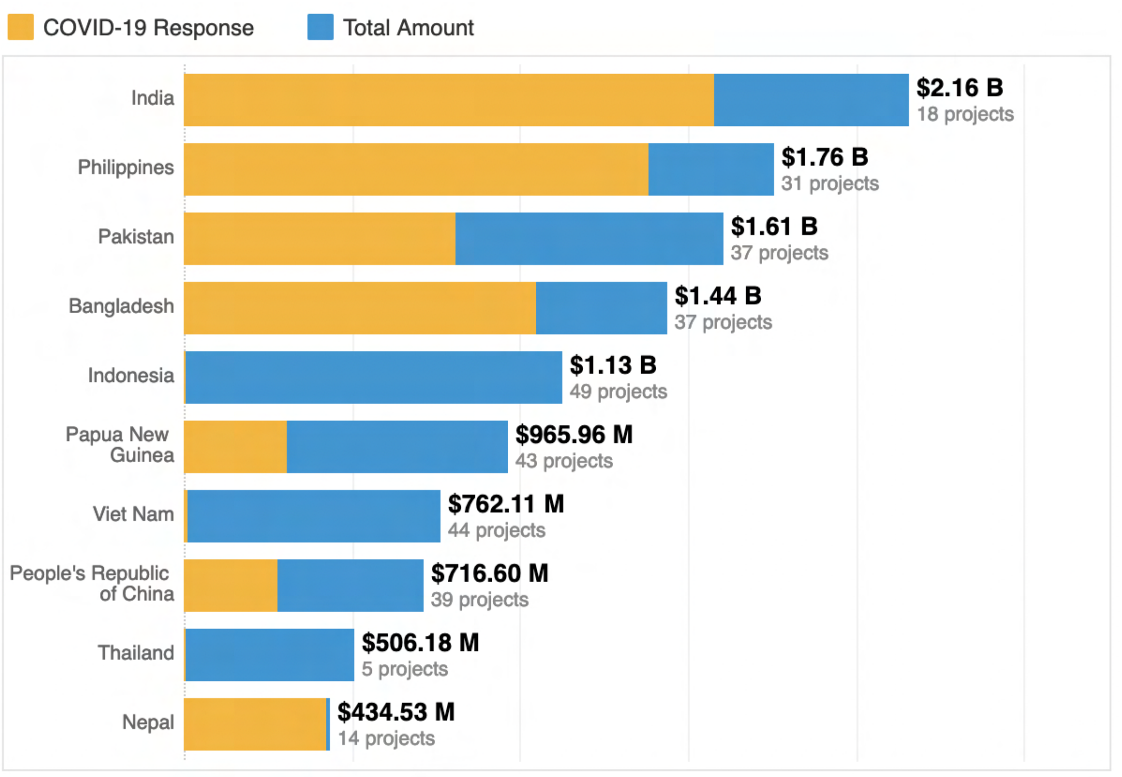
Threats due to pandemic

In response to the economic, social, and health costs of the pandemic, the ADB has committed to providing more than US$20 billion in funds to its DMCs. In 2020, the ADB launched a US$9 billion Asia Pacific vaccine facility to ensure the region receives access to affordable COVID-19 vaccines.[27] Cumulative commitments for health in recent years have been largely dedicated to the COVID-19 response (see Figure 2). This further emphasises the trend that COVID-19 has put pressure on funding for other areas of public health. The capacity of PPR varies across the region, with some countries having an effective early response to COVID-19, whilst others have been pushed to their limit.

Figure 2: ADB's Cumulative Commitments for Health as of April 2022[28]



Even as Asia and the Pacific recover from COVID-19, infectious diseases will continue to pose a serious public health threat in the region. As part of the Health Financing Partnership Facility, set up in 2013 to help DMCs improve their health outcomes, the ADB has established the Regional Malaria and Other Communicable Disease Threats Trust Fund.[29] This fund has strengthened leadership, increased financing, enhanced the quality of medicines, improved information systems, and bolstered laboratory diagnostics and surveillance.

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[27] ADB, 'ADB's Work in Health,' 2023, https://www.adb.org/what-we-do/topics/health/overview
[28] ADB, 'ADB's Work in Health,' 2023, https://www.adb.org/what-we-do/topics/health/overview
[29] ADB, 'Regional Malaria and Other Communicable Disease Threats Trust Fund: Final Report,' 2018, https://www.adb.org/publications/malaria-trust-fund-report

The value of Earth Observation (EO) for public health

Potential use cases

In the face of these wide-ranging issues, there is an opportunity for EO to support investments and interventions in public health around the world. This section outlines potential use cases for EO technology in addressing public health challenges and in supporting the activities of the IFIs profiled in the previous section.

Table 1: Potential Use Cases and Case Study Examples of EO Supporting Health

Public health challenges	Potential use cases	Case study examples
Strengthening health systems and the delivery of health services	Geo-enabled microplanning	1
	Situational awareness in anticipation of and during recovery from health emergencies	2 and 3
Controlling disease outbreaks through environmental monitoring	Monitoring climatic conditions to improve surveillance, prevention, and control of infectious diseases	4, 5, and 6
Managing extreme weather events	Modelling/surveilling air temperature to estimate the impact on people living in cities	7
Understanding air quality and its implications for health	Estimating health-related risks from air quality	2 and 8

Strengthening health systems and the delivery of health services

EO data has the potential to overcome some of the challenges faced in the provision of healthcare, especially those exacerbated by emergencies such as the pandemic, and may be fundamental to overcoming some of the inequities in healthcare provision, both between and within countries. Satellite data can be obtained for free, making it useful in these post-pandemic times when healthcare is underfunded, particularly in LMICs where financial resources may be limited. EO data has been beneficial in two main ways: by facilitating **geo-enabled microplanning** and **situational awareness in anticipation of and during recovery from health emergencies**.

Geo-enabled microplanning

Geo-enabled microplanning involves the use of geospatial data, including Geographic Information Systems (GIS), to plan and monitor service delivery at the local level of healthcare facilities. It allows healthcare providers to identify gaps in access to care within a population and plan accordingly. Data derived from EO satellites, used in conjunction with field data, helps prioritise and characterise areas for microplanning. The timely and comprehensive nature of high-resolution satellite imagery ensures that even the most vulnerable or remote populations are mapped. Case study 1 shows how the WHO combines spatial population data, healthcare facility locations and capacities, travel times, and work plans to ensure a more equitable distribution of COVID-19 vaccines. In partnership with the WHO, DevGlobal has developed Replicable AI for Microplanning (RAMP), an open-source deep-learning model designed to digitise building footprints in LMICs.[30] These digital microplans use satellite imagery to delineate areas for health service delivery planning. RAMP can provide healthcare workers with building footprints to support the delivery of vaccines and estimate disease risk exposure.

Situational awareness in anticipation of and during recovery from health emergencies

Satellite EO data can be captured in real-time, which is particularly important during emergency response. During the pandemic, EO data offered near real-time situational awareness for the public and authorities, sharing information on public health, safety, and security measures. Media reports on COVID-19 leveraged the scientific value of EO data and visual appeal of satellite imagery to attract the public's attention. Case study 2 shows how EO was used to assess the impact of government-dictated measures such as mask-wearing and travel restrictions on COVID-19 transmission. Such information could provide local governments with insights into the effectiveness of measures in future pandemics. For example, EO data can assess whether lockdowns are reducing activity through the detection of nighttime lights (NTL), as in Case study 3.

Case study 3 also demonstrates how EO satellites can be used to indicate the socioeconomic burden of the pandemic and determine when normal activities have resumed. The pandemic has given researchers, policymakers, and citizens a unique opportunity to use satellite imagery to analyse and observe sudden changes in human behaviour, understand the impact of these changes on the environment and air quality, and assess ensuing effects on public health. The ESA's Rapid Action Coronavirus and EO platform, launched in 2020 and rebranded in 2022 as Rapid Action for Citizens with EO (RACE), uses freely available data from Copernicus to assess the impact of lockdowns on transport, pollution, and socioeconomic factors, and to monitor Europe's post-lockdown recovery.[31]

Additionally, a study conducted to assess the significant racial disparities in SARS-CoV-2 infection rates across the United States drew on EO information.[32] The study used satellite imagery to assess the ratio of green space by land-cover type and neighbourhood-level data on infection rates of white versus non-white individuals to measure cross-sectional associations between racial disparity in infection rates and green spaces. After controlling for socioeconomic, pre-existing chronic diseases, and other demographic factors, the study found that a higher ratio of green spaces is significantly associated with a lower racial disparity in infection rates. Such information can be useful in efforts to reduce racial disparity during a pandemic, in this case by supplying green spaces in urban areas and natural green space across counties.

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[30] R. Price, 'Introducing the RAMP Project,' 2022, https://dev.global/2022/02/01/introduction-replicable-ai-for-microplanning/#:~:text=Our%20Replicable%20AI%20for%20Microplanning,for%20their%20regions%20of%20interest
[31] A. Anghelea A., Rapid Action on COVID-19 and Earth Observation,' 2015, https://www.copernicus.eu/sites/default/files/2021-09/September%2015_14h40_Anca%20Anghelea.pdf
[32] Y. Yang et al., 'Association of Neighborhood Racial and Ethnic Composition and Historical Redlining With Built Environment Indicators Derived From Street View Images in the US,' JAMA Network Open 6, no. 1 (2023): e2251201, https://pubmed.ncbi.nlm.nih.gov/36652250/

Controlling disease outbreaks through environmental monitoring

Public health initiatives have shifted their focus from treating diseases to preventing them by surveillance and promoting healthy behaviours. As shown in the Background section of this report, the changing natural environment is impacting public health. Thus, the monitoring of environmental, socioeconomic, and meteorological factors that impact public health, as well as the mechanisms that interconnect these, is key to understanding what factors influence diseases and preventing people from contracting them.

Collecting in-situ data on factors that cause or exacerbate diseases is complicated, even in countries with extensive monitoring networks. Ground monitoring instruments are costly, often change over time, and are not harmonised across countries. Satellites provide current, near real-time data on a variety of different factors that can impact diseases, enabling understanding of the factors that influence diseases and use of this knowledge to predict future outbreaks and spreads. Moreover, the global reach of EO makes it particularly valuable for monitoring factors that impact public health in areas where ground-based measurements are limited or absent.

Monitoring climatic conditions to improve surveillance, prevention, and control of infectious diseases

Tele-epidemiology uses space-based systems, such as satellite imagery or remotely sensed data, to study the interaction between the environment, ecosystem, and other factors responsible for diseases in humans, animals, and plants. EO can reveal associations between diseases or disease vectors and remotely sensed parameters, as well as the dynamic ecosystem processes of public health threats. Leveraging these associations, public health institutions can map risk factors and predict the emergence, re-emergence, and spread of disease. This allows them to generate early warning systems, better control an epidemic, respond faster to disease outbreaks (response actions) and prevent or mitigate the spread and emergence of diseases (disease preparedness), all critical components of infectious disease prevention.

The continuous and precise nature of EO has been particularly useful in creating risk maps for vector-borne diseases. A risk map identifies where an environment is suitable for the populations of vectors to become established. The identification and monitoring of vector populations are integral to global vector-borne disease surveillance efforts. EO data could play a key role in identifying risk locations for mosquito-borne diseases globally by monitoring habitat and climate variables. Most research on the use of EO for mosquito-borne diseases has taken place in an academic setting. However, EO is increasingly used in mosquito-borne disease control programmes, especially for malaria and dengue fever.

A majority of malaria cases (95%) and deaths (96%) occur in Africa.[33] The MALAREO project (see Case study 4), implemented in Africa, provides pivotal insights into the use of EO data for malaria control. This includes mapping mosquito breeding sites and identifying malaria transmission hotspots. Additionally, half the world's population is at risk of dengue fever, a mosquito-borne viral infection prevalent in tropical and sub-tropical climates.[34] The Dengue Forecasting Model Satellite-

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[33] WHO, 'Malaria,' 2023, https://www.who.int/news-room/fact-sheets/detail/malaria
[34] G. Tsarouchi, 'D-MOSS: Dengue forecasting Model Satellite-based System,' 2020, https://www.hrwallingford.com/projects/d-moss-dengue-forecasting-model-satellite-based-system

based System (D-MOSS), funded by the UK Space Agency, evaluates dengue fever risk at the district level and can cover entire countries (see Case study 5). Using satellite data, D-MOSS assesses environmental and meteorological conditions conducive to the spread of dengue, offering targeted insights for outbreak prevention.

There are other infectious diseases (i.e., those that are not mosquito-borne) that can be prevented using data gathered from EO satellites. For instance, cholera is an acute diarrhoeal infection caused by eating food or drinking water that is contaminated with the vibrio cholera bacterium. In 2016, the US National Aeronautics and Space Administration (NASA) developed a forecasting tool leveraging EO data to predict cholera outbreak potentials. This model, first tested in Yemen, utilises satellite data on temperature, water quality, and precipitation patterns to effectively anticipate cholera risks (see Case study 6). This initiative underscores EO's significant value, especially in regions like Yemen, where ground-based cholera monitoring is challenging, and exemplifies how satellite data can fill critical gaps in epidemic surveillance and response planning.

Managing extreme weather events

High temperatures and drastic changes in heat pose serious threats to public health. Climate change is increasing the frequency and duration of heatwaves. This, along with the increase in the urban heat island effect and the rapid growth of urban populations, is increasing health risks to urban populations.

Modelling/surveilling air temperature to estimate the impact on people living in cities

Monitoring air temperature is essential to creating climate-resilient and liveable cities. Satellites can monitor heatwaves and estimate their impact on urban populations. EO data can help inform which areas should be prioritised for potential investment in nature-based solutions, as well as help analyse the impact of such investments after implementation.

Case study 7 shows how satellite data can help build a more reproducible heat-health vulnerability (HHV) system, which is used to identify high-vulnerability areas around the world and assist governments in formulating targeted policies to reduce mortality during heatwaves.

Understanding air quality and its implications for human health

Estimating health-related risks from air quality

The surveillance of global air quality requires high-quality data with high spatial resolution and global, standardised, and continuous coverage over long periods. Satellites offer a range of EO data that can facilitate the assessment of air quality everywhere on Earth, with consistent measurements across time and space. This data can guide decision-making to help prevent deaths related to air quality and mitigate its impact on public health.

The following are three examples of ways in which satellites assess air quality:

1. **The direct measurement of air pollutants**: For example, NASA's Ozone Monitoring Instrument (OMI) provides real-time and historical measurements of the levels of O_3, sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and aerosols. Similarly, ESA's TROPOMI satellite instrument collects data on atmospheric constituents important for air quality monitoring, including carbon monoxide (CO), methane (CH_4), O_3, SO_2, and NO_2. The spatial

coverage of these satellite instruments is far larger than surface monitoring networks, which increases their statistical power in inferring a relationship between pollutants and health outcomes. Satellite data is transforming the assessment of air pollution exposure and its impact on health (see Case study 8).

2. **The prediction of dust storms**: Dust storms can lead to unhealthy air conditions, exacerbate health conditions, and increase hospital admissions. Satellites help predict dust storms, providing warnings to healthcare professionals and the public. For instance, medical researchers used dust maps created by ESA to monitor large dust storms in Africa's Sahel region to better understand deadly meningitis outbreaks.[35] While the precise link between dust storms and epidemics is still being researched, these satellite-derived maps enable weekly monitoring of dust storms and the conditions that might lead to an outbreak.

3. **The identification of wildfires**: Satellite images of wildfires can be used to create smoke forecasts and estimate air quality. For example, EO data from the polar-orbiting Moderate Resolution Imaging Spectroradiometer (MODIS) satellite sensors can identify fire location and intensity in near real-time, allowing for the prediction of emissions. In response to devastating wildfires in summer 2023 in Greece, Italy, Spain, Portugal, Algeria, Tunisia, and Canada, resulting in loss of life, ESA upgraded its World Fire Atlas, providing a comprehensive analysis of wildfires across the globe. The interactive dashboard allows individuals to examine the occurrence of fires and analyse their progression over time. Launched in 2019, the atlas has been a valuable tool for European civil protection agencies and firefighters.

[35] ESA, 'Satellites monitoring dust storms linked to health risk,' 2005, https://www.esa.int/Applications/Observing_the_Earth/Satellites_monitoring_dust_storms_linked_to_health_risk

Case studies

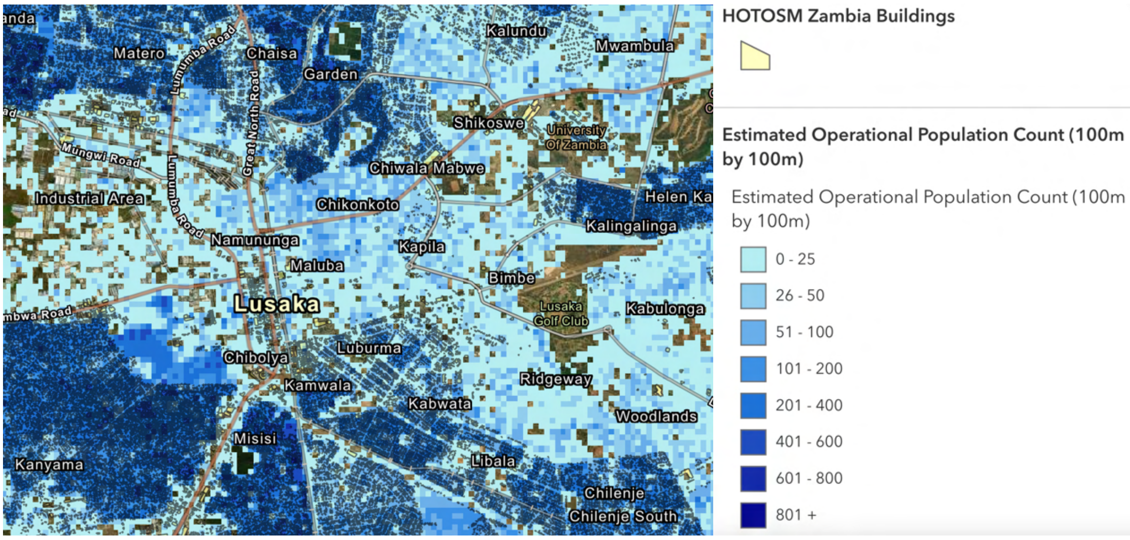
Case study 1: GEO-enabled microplans in action across Zambia

As the international coordinator for COVAX,[36] the WHO implements comprehensive digital planning to secure equal access to vaccines. In partnership with researchers, governments, the private sector, and NGOs, the WHO uses GIS to create detailed digital microplans that include essential information, such as the location of healthcare facilities and underserved communities, population spread, and strategies for reaching every household.

Examples of the necessary datasets for COVID-19 vaccination microplanning were created for Zambia. Using data provided by Geo-Referenced Infrastructure and Demographic Data for Development (GRID3),[37] the following information was generated and enabled the team to devise strategies to guarantee comprehensive vaccine coverage without exclusions:

1. Community-level population data (see Figure 3): Local health workers and community volunteers in Zambia collected information on the number, age, and distribution of the population within an area. This information was essential to identify and map priority groups, such as the elderly and healthcare workers.

Figure 3: Map of Lusaka Showing the Estimated Operational Population Count (100m by 100m)[38]



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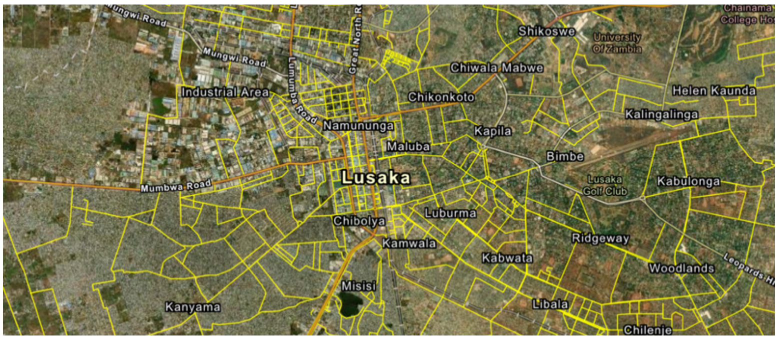
[36] COVAX, the immunization component of the Access to COVID-19 Tools (ACT) Accelerator, is led by CEPI, Gavi, the Vaccine Alliance, and WHO, with support from the Bill & Melinda Gates Foundation and UNICEF. It aims to expedite the development of effective vaccines for all nations while also promoting the establishment of manufacturing infrastructures and the advanced procurement of supplies.
[37] GRID3 collaborates with governments, the UN, academia, and the private sector to develop geospatial solutions tailored to each country's development needs. Implemented by the Center for International Earth Science Information Network at Columbia University, the Flowminder Foundation, the UN Population Fund (UNFPA), and WorldPop at the University of Southampton. GRID3 has received support from the Bill & Melinda Gates Foundation, the UK Foreign, Commonwealth & Development Office (FCDO), Gavi (the Vaccine Alliance), UNICEF, and WHO.
[38] WHO GIS Center for Health, 'Cutting Edge GIS Technologies for COVID-19 Vaccine Delivery,' 2021, https://storymaps.arcgis.com/stories/7b3e36d2f4a04eaf9be1c3cb936e6681

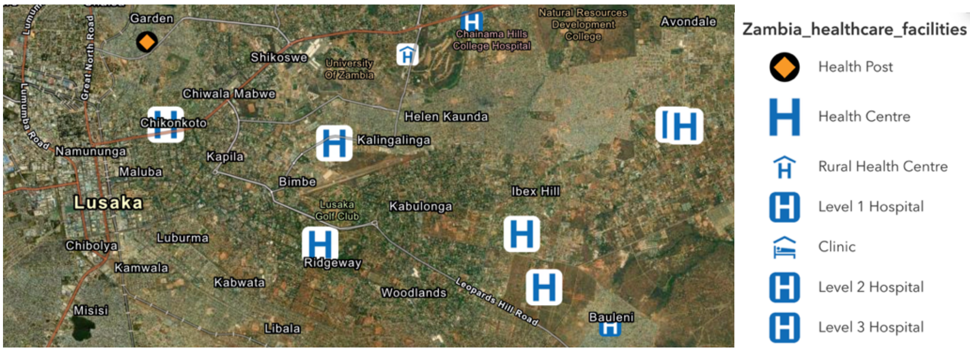
2. Road networks (see Figure 4): Satellite data was used to help estimate travel time and assess the best ways to reach communities. This data was combined with precipitation data to account for washed-out unpaved roads.

Figure 4: Map of Satellite-Derived Road Networks in Lusaka[39]



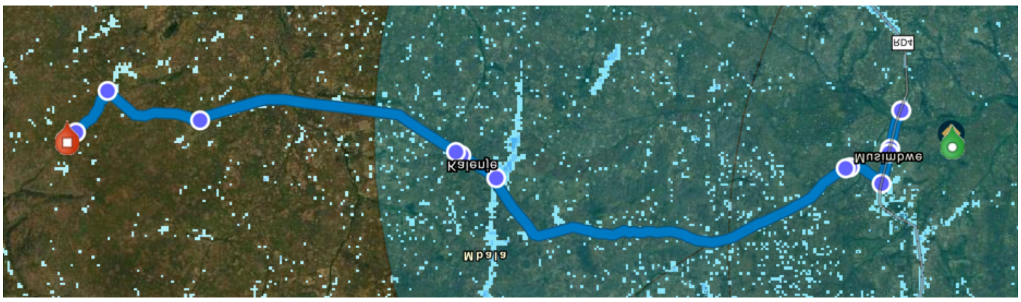
3. Healthcare facility locations and capacities (see Figure 5): This information helps the WHO assess how many people each facility can vaccinate.

Figure 5: Map of Healthcare Facilities in Lusaka[40]



4. Catchment areas (see Figure 6): These are geographical areas served by healthcare facilities. By delineating catchment areas, healthcare providers can more effectively plan mobile clinics as designated vaccination sites for communities outside of these areas that do not have adequate access to a healthcare facility.

Figure 6: Map of Catchment Areas and Potential Sites for Mobile Clinics[41]



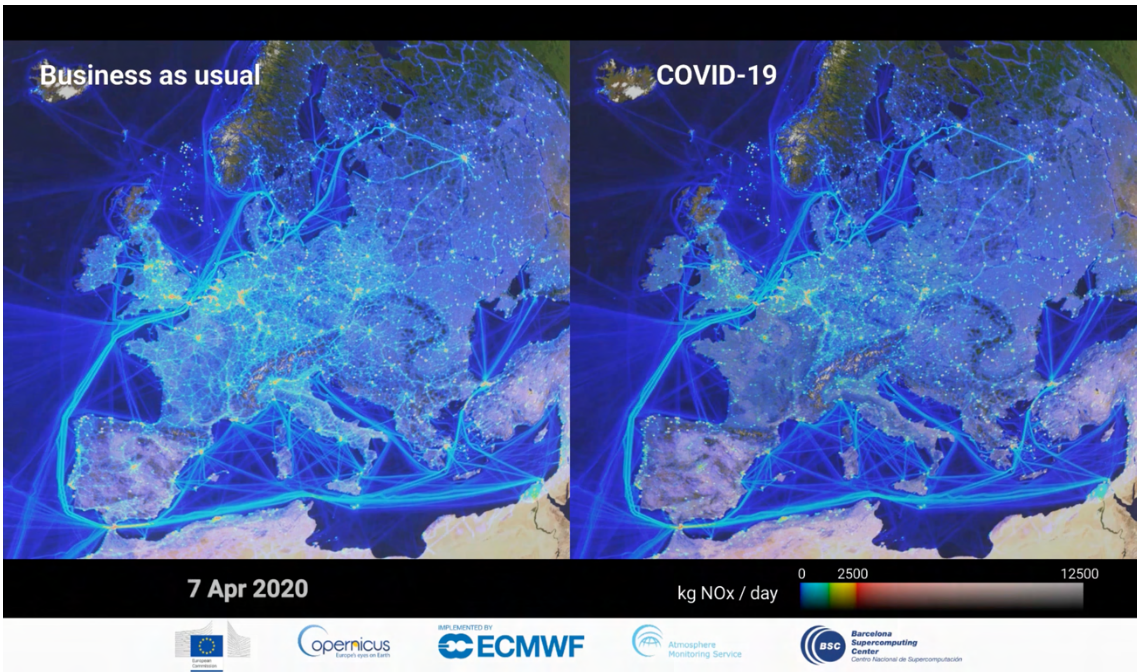
[39] Ibid.
[40] Ibid.
[41] Ibid.

Case study 2: Understanding the links between lockdown policies, air pollution, and related mortality across Europe

The Copernicus Atmosphere Monitoring Service (CAMS), one of six services that comprise Copernicus, provides reliable, quality-assured, and globally accessible datasets concerning air quality and health, solar energy, and greenhouse gases, and their impact on the climate. CAMS is operated by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission and funded by the EU. Forecasts enabled by CAMS are directly applicable in their current form and act as foundational data for other services, including national air quality predictions, mobile apps, and policymaking tools. Consequently, information from CAMS on global pollution and air quality across Europe benefits millions of users.

In response to a growing call for detailed assessments of the impact of the COVID-19 lockdown on environmental and air quality conditions, CAMS partnered with the Barcelona Supercomputing Centre (BSC) to gain more comprehensive insights into the decline in emissions across Europe during the pandemic's initial outbreak. Figure 7 illustrates the CAMS simulation of the concentration of nitrogen oxides (NOx) in two different scenarios: business as usual and lockdown. CAMS confirmed that lockdown measures during the initial phase of the COVID-19 pandemic led to decreases in NOx and CO_2 emissions from fossil fuels across Europe. Using AI, the research provides a detailed daily analysis of emissions by sector and location, along with insights into the contributions of various countries and the types of pollutants involved.

Figure 7: Animation of the Absolute Cumulative NOx Emission Decline in 2020 vs the Business-As-Usual Scenario (10 April 2020)[42]



[42] Copernicus, 'Study confirms reductions in emissions during the first wave of COVID-19 in Europe,' 2020, https://atmosphere.copernicus.eu/copernicus-study-confirms-reductions-emissions-during-first-wave-covid-19-europe

Contact us via gda@esa.int

Another study employed the CAMS operational air quality framework to assess the impact of specific lockdown policy measures on the reduction of pollution levels. The researchers measured the levels of NO_2, O_3, $PM_{2.5}$, and PM_{10} in 47 European cities and estimated associated short-term mortality rates during the designated period. The findings revealed the following: [43]

- Lockdown policies led to a reduction in air pollution levels, with NO_2 being the pollutant with the largest decline.
- Government actions linked to the closure of schools and workplaces, limitations on gatherings and requirements to stay at home had the highest impact, whilst policies that banned national and international travelling seemed to have been less successful in lowering pollution.
- The reduction in NO_2, O_3, $PM_{2.5}$, and PM_{10} could have avoided 486 deaths (related to NO_2), 37 (related to O_3), 175 (related to $PM_{2.5}$), and 134 (related to PM_{10}).

The results of the study offer insights into the success of governmental restrictions and specific policies in lowering air pollution levels in cities, as well as the health advantages of minimising exposure to elevated air pollution across the continent.

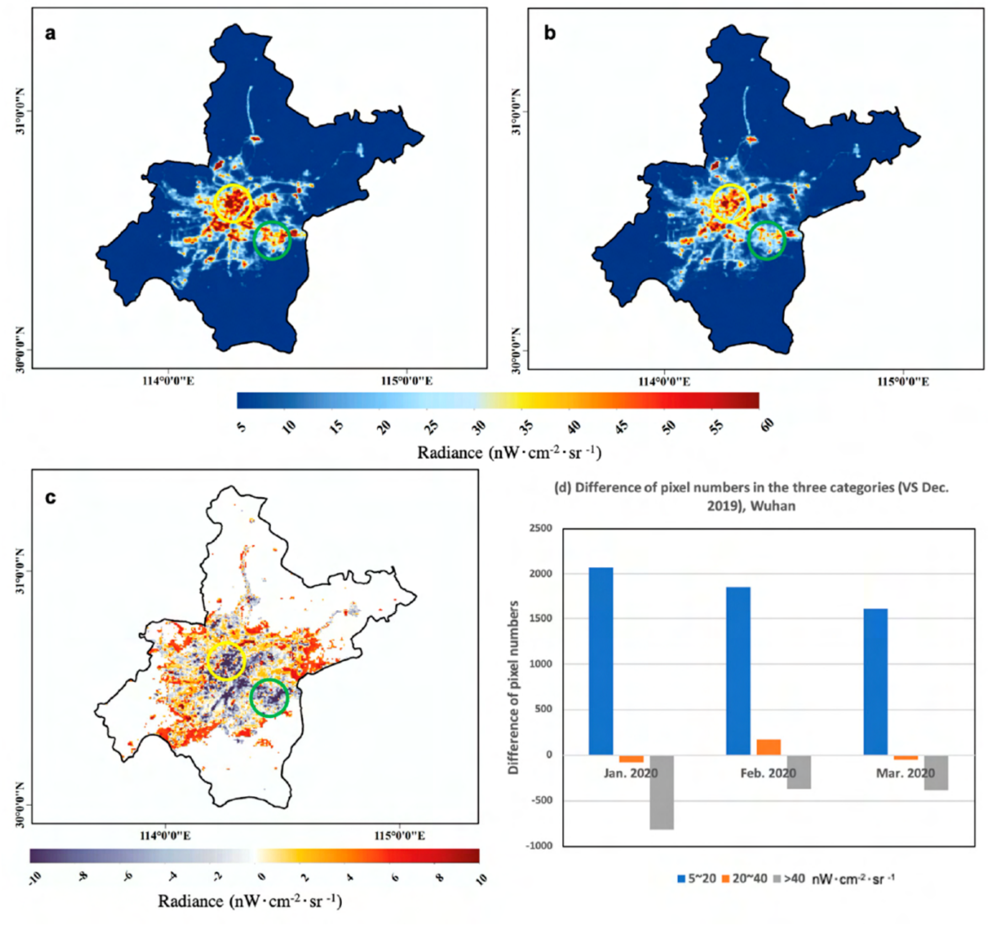
Explore GDA #AcceleratingImpact at gda.esa.int

[43] R. Schneider et al., 'Differential impact of government lockdown policies on reducing air pollution levels and related mortality in Europe,' Scientific Reports 12 (2022): article 726, https://www.nature.com/articles/s41598-021-04277-6

Case study 3: Using spatiotemporal data to assess responses to COVID-19 in Wuhan

In 2020, a research paper examined the impact of COVID-19 on human activities, lifestyle changes, and environmental conditions by analysing the spatial and temporal dynamics of nighttime lights (NTL) and air quality in mainland China before and during lockdowns. The study found that the number of pixels with NTL detection increased in residential zones and decreased in commercial centres across most provinces following the lockdown. A detailed examination of Wuhan, the initial epicentre of the outbreak, revealed that the two most prosperous and crowded areas of Wuhan, Jianghan and Guangu (represented by the yellow and green circles respectively in Figure 8), dimmed, signifying that there was less activity during the lockdown in February 2020 (see Figure 8b), compared to pre-lockdown in December 2019 (see Figure 8a). In turn, residential areas outside the commercial centres were brighter in January 2020 (see Figure 8c).

Figure 8: Difference between Monthly Average NTL Radiance of Wuhan Before and After Lockdown[44]

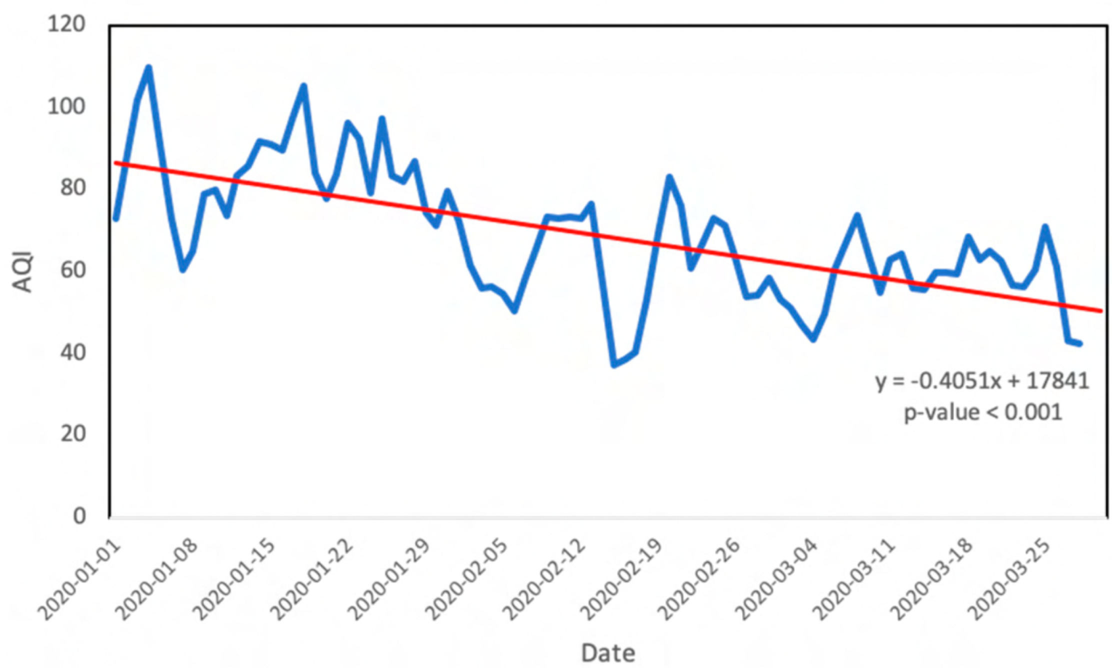


[44] Q. Liu et al., 'Spatiotemporal Patterns of COVID-19 Impact on Human Activities and Environment in Mainland China Using Nighttime Light and Air Quality Data,' Remote Sensing 12, no. 10 (2020): article 1576, https://www.mdpi.com/2072-4292/12/10/1576

Residential areas enforced stay-at-home orders less strictly than commercial inner-city areas during the lockdown. This suggests that, without directives from governing bodies, physical distancing might be less likely to occur.

Furthermore, the study found that between January and March 2020, the daily average air quality index declined, indicating improved air quality (see Figure 9). The pandemic significantly altered daily routines and mobility, a change propelled by stringent lockdown and quarantine measures. Concurrently, air quality in mainland China improved due to decreased industrial operations and vehicle use. These findings underscore the comprehensive and strict quarantine measures China implemented to manage the pandemic, offering valuable lessons for global pandemic responses.

Figure 9: China Air Quality Index Trend Before and During the Pandemic[45]



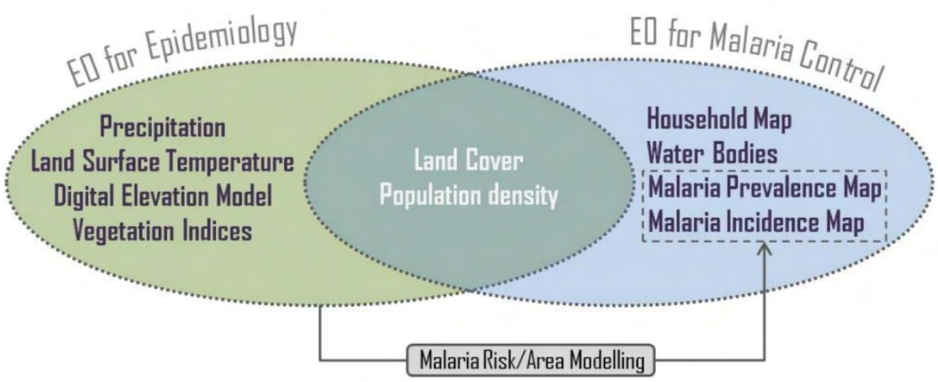
[45] Q. Liu et al., 'Spatiotemporal Patterns of COVID-19 Impact on Human Activities and Environment in Mainland China Using Nighttime Light and Air Quality Data,' Remote Sensing 12, no. 10 (2020): article 1576, https://www.mdpi.com/2072-4292/12/10/1576

Case study 4: Using EO and Geographic Information Systems (GIS) for malaria control programs in Africa

MALAREO, a two-year project partly funded by the European Commission, explored the use of remote sensing in malaria control across the transnational area that includes southern Mozambique, eastern Eswatini (formerly Swaziland), and northeastern South Africa. The absence of malaria control programmes in the past, coupled with the increased resistance to antimalarial drugs, has impeded development in the region. The objective of MALAREO was to enhance the management of vector control within this region by integrating EO and GIS capabilities into malaria control strategies. The project aimed to foster greater integration and recognition of EO solutions within local and national malaria control programmes (NMCPs), thereby establishing a foundation for an EO monitoring cell to bolster malaria control efforts. Furthermore, MALAREO sought to push the boundaries of malaria research and facilitate the operational application of EO products and solutions in vector control, establishing new standards in the field.

Reflecting user needs and the latest advancements in EO for malaria, the developed products are categorised into two types of EO applications: Epidemiology and Support for Malaria Control (see Figure 10). These two categories share thematic intersections, meaning some products serve both as inputs for epidemiological modelling and for the direct assistance of NMCPs.

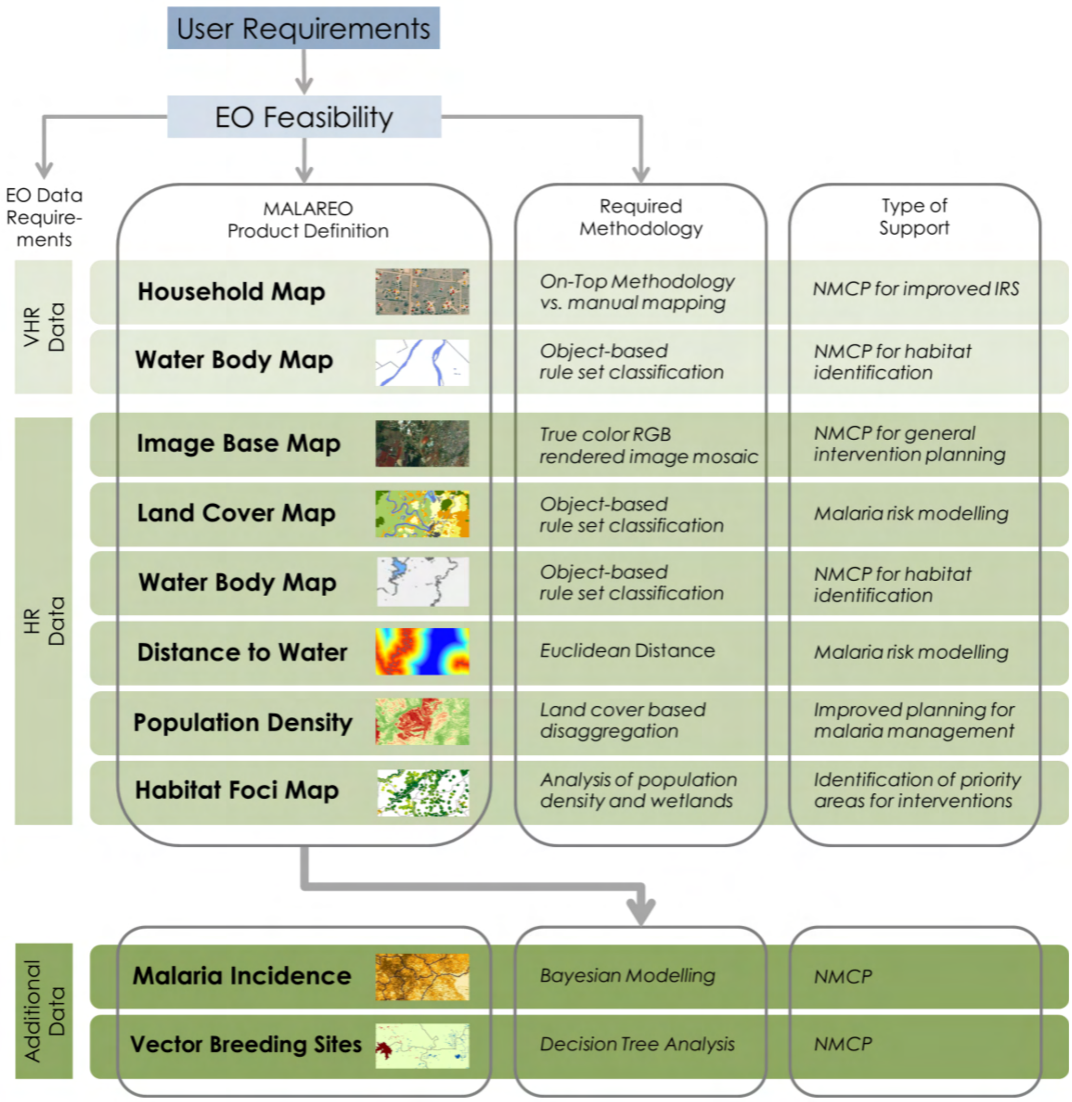
Figure 10: General MALAREO Overview of Parameters Derived from Remote Sensing for the Two EO Applications (Epidemiology and Malaria Control Management)[46]



Ten different map types were developed, including water body maps, land cover maps, and population density maps (see Figure 11). These were produced from a variety of medium, high, and very high-resolution EO data.[47] The resulting MALAREO MapBook improved integrated vector control management, enabling health officials to plan indoor residual spraying (IRS) and distribute insecticide-treated nets (ITN) more effectively. To build regional capacities, a core group of end users was trained to a moderate to high level of competency in applying these products, enabling them to subsequently train their colleagues.

[46] CORDIS, 'EO in Malaria Vector Control and Management,' 2013, https://cordis.europa.eu/project/id/262887/reporting/es
[47] A detailed methodology for MALAREO including all input EO and ancillary data is available here: https://cordis.europa.eu/project/id/262887/reporting/es

Figure 11: MALAREO Product Description[48]



In January 2013, a pivotal demonstration event was held in South Africa for end users from the South African NMCP. This event showcased the outcomes of the MALAREO project and their immediate and future significance. The presentation of MALAREO's EO products highlighted their value in enhancing malaria control strategies. These EO products are pivotal for refining planning processes and represent a significant step towards creating an early warning system for malaria by integrating environmental and epidemiological data.

During the project's second phase, three training sessions, which received overwhelmingly positive feedback, were conducted. The use of open-source GIS software in these courses promised a direct, positive impact on the efficacy and organisation of MCPs.

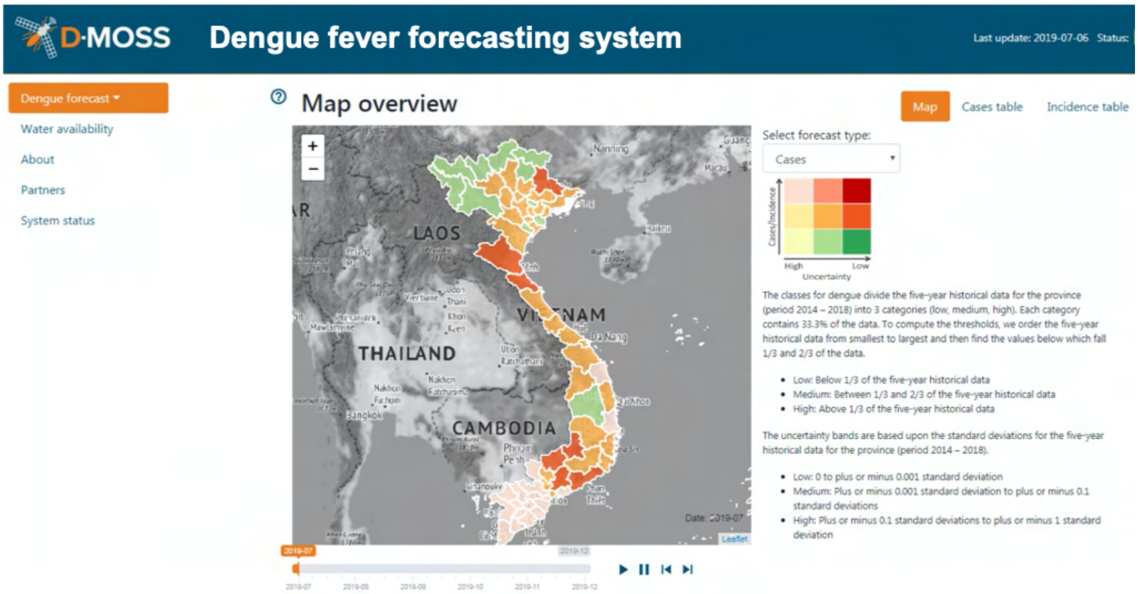
[48] CORDIS, 'EO in Malaria Vector Control and Management,' 2013, https://cordis.europa.eu/project/id/262887/reporting/es

Case study 5: Forecasting dengue using EO in Vietnam

The Dengue forecasting Model Satellite-based System (D-MOSS), a climate-driven early warning system funded by the UK Space Agency's International Partnership Programme (IPP), was co-designed with the United Nations Development Programme (UNDP) and WHO. By integrating EO data with weather forecasts and hydrological models, D-MOSS can estimate future dengue outbreaks up to eight months in advance. A unique component of the system is its ability to predict water availability, which is commonly overlooked in dengue forecasting models. Water availability is particularly useful when integrated with other critical factors (e.g., land cover, rainfall, and temperature) to enhance disease incidence predictions.

With support from IPP and under the leadership of HR Wallingford, D-MOSS was implemented in Vietnam in 2019 (see Figure 12).

Figure 12: D-MOSS Map Overview in Vietnam Identifying Low, Medium, and High-risk Regions[49]



Vietnam lacked a predictive system for dengue outbreaks, a situation that has worsened as dengue cases have doubled since 2000, due largely to ineffective control of the *Aedes aegypti* mosquito. With dengue trends worsening regionally, the introduction of a seasonal forecasting system based on EO data would significantly aid the Vietnamese government in implementing cost-effective, early intervention strategies. Additionally, Vietnam faces significant water management challenges. Two-thirds of the country's water originates in neighbouring countries and flows through seven of the nine major transboundary river basins. Increased upstream usage worsens these conditions. Thus, an EO-based system for water availability was needed in Vietnam to improve its transboundary water resources monitoring and management.

D-MOSS uses UK Met Office seasonal forecasts and a set of freely available optical and radar EO data from GPM (NASA/ JAXA), Sentinel and SMOS (ESA), SMAP, and Aqua/Terra (NASA). This

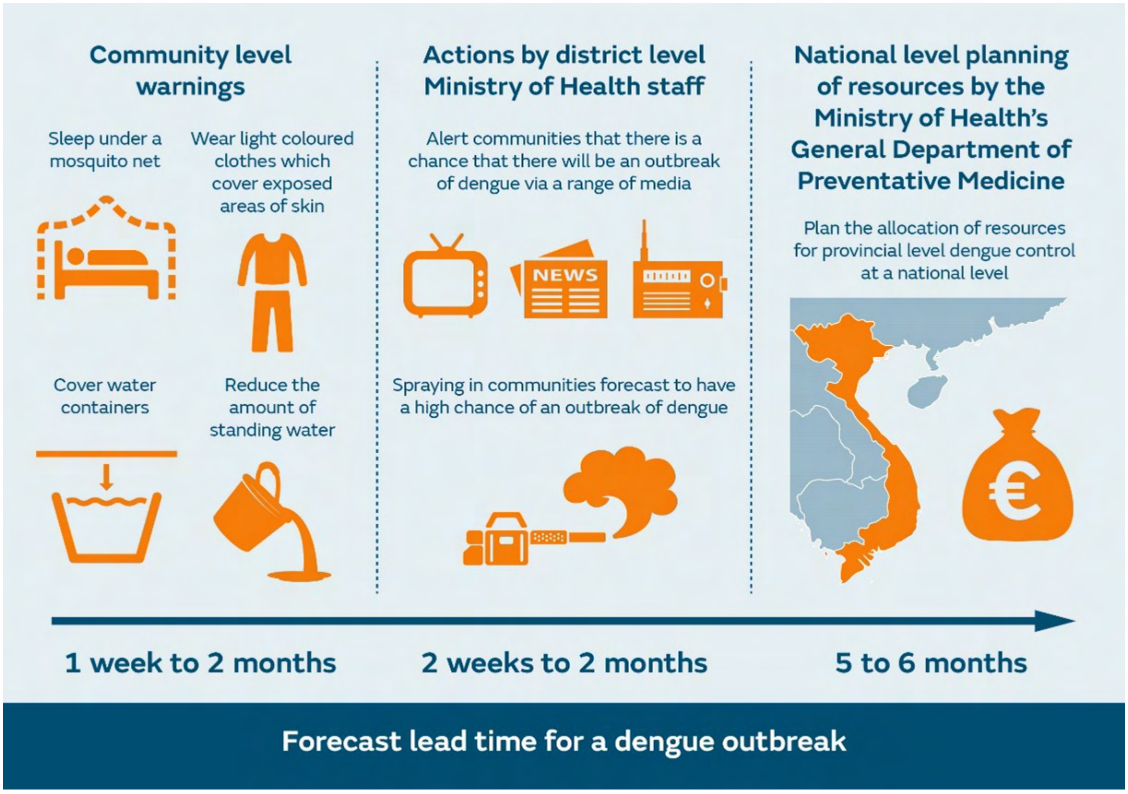
[49] A. Kaiser, 'Dengue MOdel Forecasting Satellite-based System (D-MOSS) (IPP funded)', 2019, https://www.spacefordevelopment.org/catalogue/dengue-mosquito-simulation-from-satellites-d-moss-hr-wallingford/

comprehensive dataset includes information on rainfall, temperature, soil moisture, humidity, population density, water availability, and land use. Such extensive data enables D-MOSS to assess both the likelihood and severity of future dengue outbreaks several months in advance.

According to feedback from end users, D-MOSS has contributed to reductions in both dengue cases and mortality rates. The successful deployment of D-MOSS in Vietnam has validated its ability to accurately predict dengue outbreaks, establishing it as a reliable and cost-efficient tool for early intervention. The challenges of dengue fever in other countries across South Asia, combined with the proven effectiveness of D-MOSS, have prompted the project's extension to Sri Lanka, Laos, Cambodia, Thailand, the Philippines, and Malaysia.

Figure 13 illustrates the proactive measures that can be implemented to prevent a dengue outbreak, showcasing the adaptability of these measures across various geographic scales and the forecast lead times provided by D-MOSS.

Figure 13: Early Actions to Prevent a Dengue Outbreak at Different Spatial Scales for Different Forecast Lead Times Provided by D-MOSS.[50]

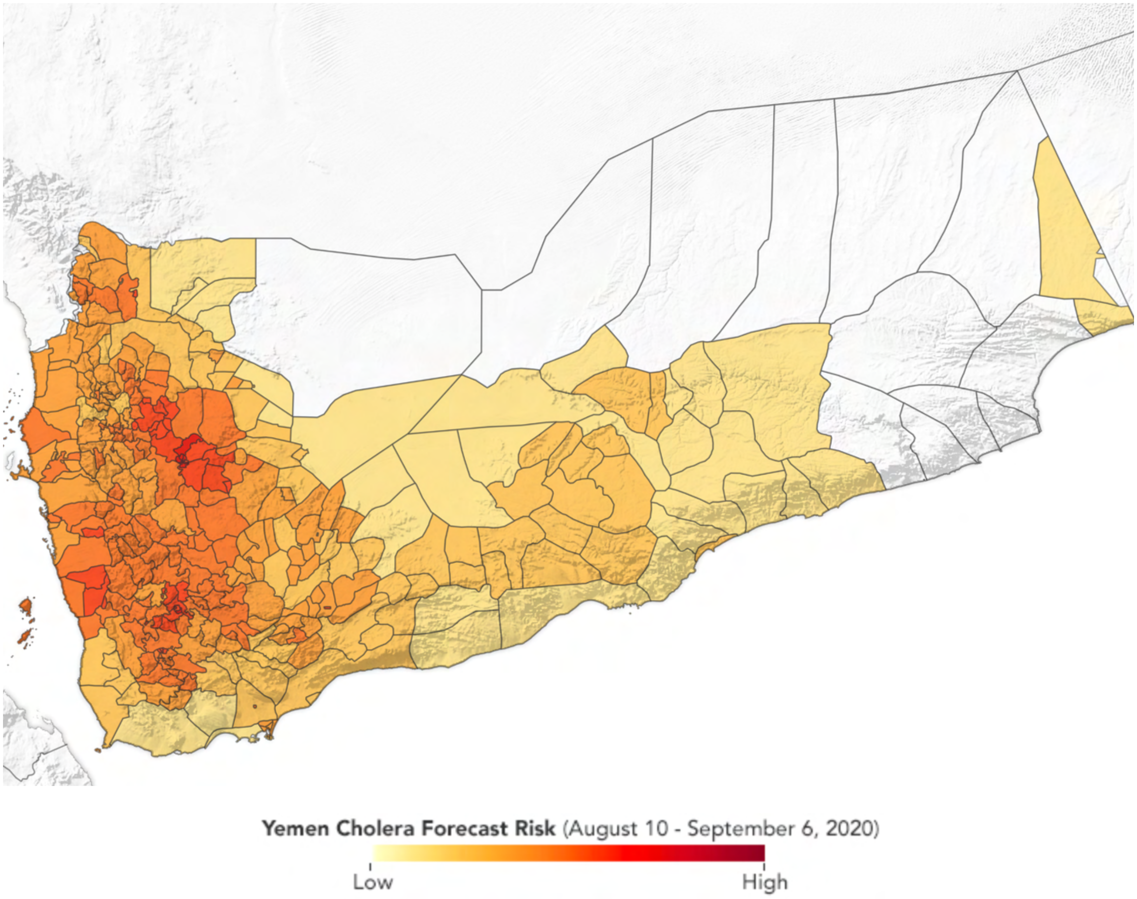


[50] UK Space Agency, 'Managing dengue fever with space technology,' 2021, https://space.blog.gov.uk/2021/09/17/managing-dengue-fever-with-space-technology/

Case study 6: Predicting cholera outbreaks in Yemen

In 2017, Yemen experienced one of its most severe cholera outbreaks, which was exacerbated by heavy rainfall, flooding, and widespread displacement due to conflict. The outbreak affected over one million individuals and resulted in at least 2,000 deaths. To prepare for future cholera outbreaks, a NASA-funded research team used satellite and terrestrial data to forecast cholera risks in Yemen and beyond. The map in Figure 14 below illustrates forecasted cholera risks in Yemen between August and September 2020 using the Cholera Prediction Modeling System. This system integrates freely available precipitation data from the GPM and TRMM missions, air temperature data from the MERRA-2 reanalysis product, and demographic information to project potential cholera outbreaks following the heavy rains in August.

Figure 14: NASA Earth Observatory Map Showing Yemen Cholera Forecast Risk (August 10 – September 6, 2020)[51]

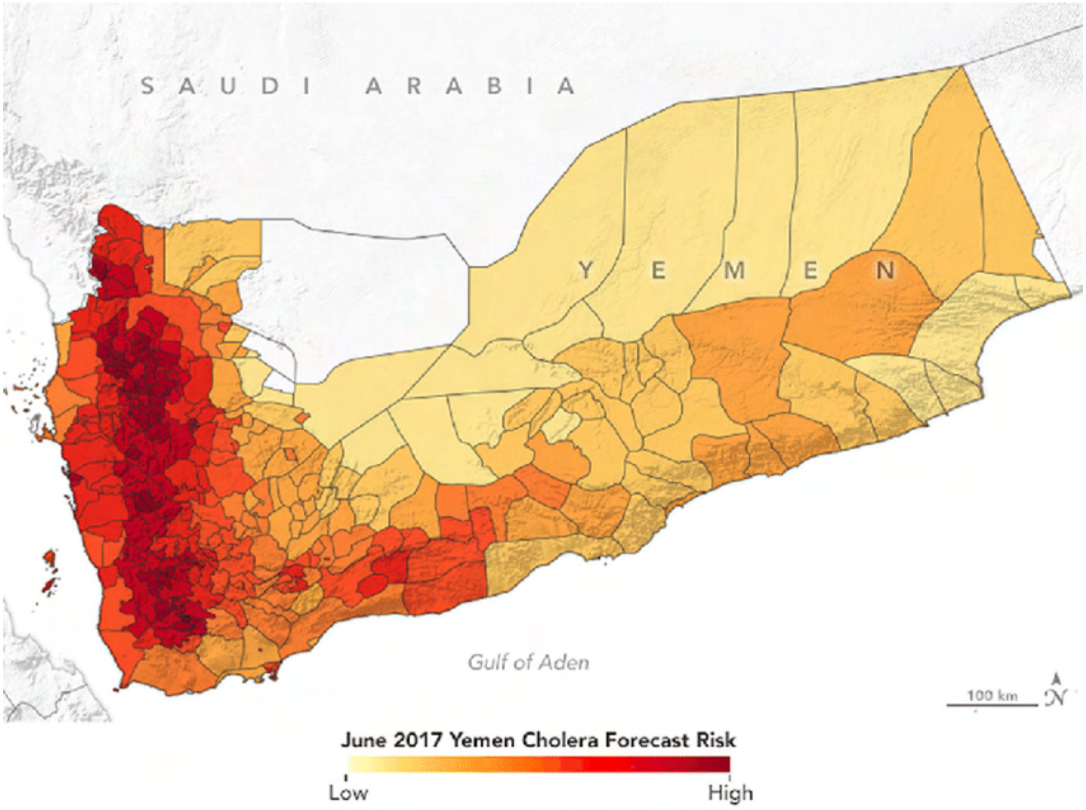


Despite challenges validating the model due to the lack of reliable health data from Yemen, the model's initial real-world application in 2017 successfully predicted a potential outbreak based on observed rain and temperature conditions (see Figure 15). Achieving a 92% accuracy rate, the

[51] K. Patel, 'Predicting Cholera Risk in Yemen,' NASA Earth Observatory, 2021, https://earthobservatory.nasa.gov/images/147101/predicting-cholera-risk-in-yemen

model not only forecasted the outbreak but also identified unexpected inland areas at risk. Following this success, the team collaborated with the UN Children's Fund (UNICEF) and the UK's Department for International Development to provide weekly outbreak forecasts to support prevention and relief efforts in Yemen.

Figure 15: NASA Earth Observatory Map Showing Yemen Cholera Forecast Risk (June 2017)[52]



This groundbreaking achievement underscored the model's global applicability, marking a significant advancement in disease forecasting. It has shed light on cholera's dual nature as both endemic, with seasonal recurrences, and epidemic, which are sudden and often linked to disasters that compromise water quality and alter human behaviours, significantly raising infection risks. Epidemic outbreaks tend to be more lethal due to the unpreparedness of the population.

Yemen's ongoing battle with cholera since 2017 has shifted from an epidemic to an endemic situation, especially in coastal areas conducive to the bacteria's survival. With over 2 million suspected cases from April 2017 to June 2020, combatting cholera in Yemen now requires the improvement of water sanitation systems to prevent it from becoming a seasonal disease.

[52] L. Kant et al., 'Disease pandemics and the threat of microbial emergence,' 2021, https://www.researchgate.net/figure/Satellite-data-in-Yemen-2017-Light-indicates-low-risk-and-dark-indicates-the-actual_fig1_356279782

Case study 7: Mapping Heat-Health Vulnerability (HHV) based on remote sensing

The World Meteorological Organization (WMO) has reported that extreme temperatures in southwestern Pakistan have exceeded 54°C in recent years. Extreme temperatures undermine the body's ability to maintain its internal temperature, leading to a range of health issues including heat cramps, heat exhaustion, heatstroke, and hyperthermia during periods of intense heat. Moreover, these heat-related extremes can exacerbate chronic illnesses, including cardiovascular, respiratory, and cerebrovascular diseases.

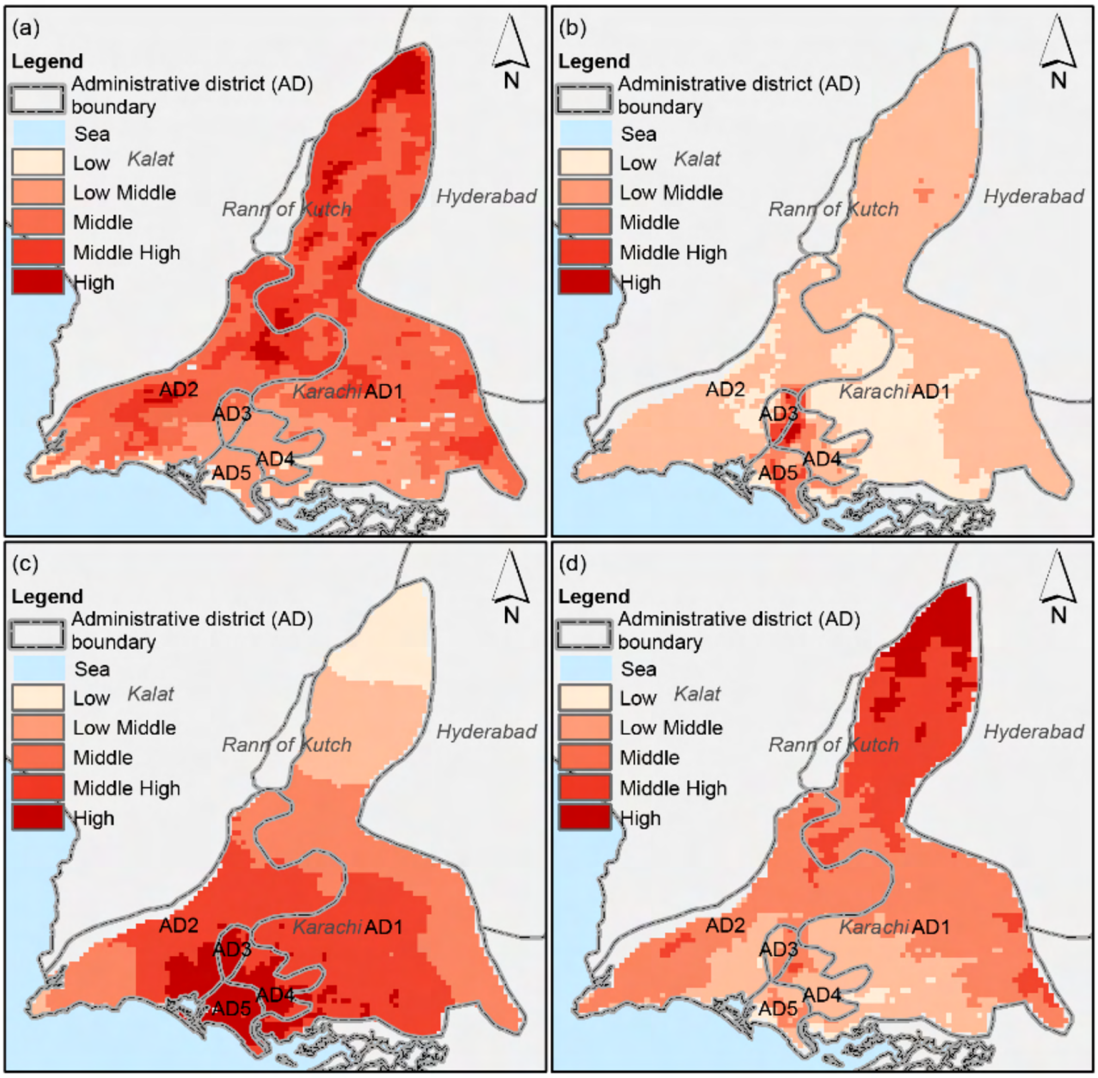
To tackle this challenge, a study was conducted to assess the use of broadly accessible spatial data to analyse HHV and its contributing factors in Karachi, Pakistan. The model aims to identify areas of high vulnerability and inform planning for corrective actions.

The case study calculates different indicators that serve as relevant evaluation factors (Figure 16):

a) Exposure: Calculated using land surface temperature data from Aqua/Terra MODIS to determine the intensity of heatwaves.
b) Sensitivity: Identifies those who are more sensitive to heatwaves, including individuals living in poverty and those over 65 years old. The study uses EO data to measure the coverage of impervious surfaces by calculating the Normalised Difference Built-up Index (NDBI).
c) Adaptability: Looks at the distance from a medical institution, vegetation coverage (calculated using MODIS/Terra vegetation indices data), GDP, and NTL data from satellites as a proxy for the level of urbanisation.
d) Vulnerability: These criteria layers were stacked to assess HHV (see Figure 16d). Karachi Central was identified as more vulnerable than other areas, largely due to its high concentration of ageing population. This is why the study suggests the local government pay more attention to this area.

The research offers valuable insights for enhancing our comprehension of HHV and for the development of identification, monitoring, and evaluation systems for heatwaves. Such advancements can assist local authorities in devising specific strategies to reduce the health impacts and fatalities associated with heatwaves. For Karachi, prioritising infrastructure development in areas with higher vulnerability and offering greater support to vulnerable populations, such as the elderly, are critical steps to minimise heatwave-related health risks and fatalities. Furthermore, the establishment of indoor cooling centres represents a viable strategy for risk mitigation.

Figure 16: Heat Health a) Exposure, b) Sensitivity, c) Adaptability, and d) Vulnerability in each Administrative District (AD) in Karachi: AD1 Malir, AD2 Karachi West, AD3 Karachi Central, AD4 Karachi East, and AD5 Karachi South[53]



[53] X. Wu et al., 'Mapping Heat-Health Vulnerability Based on Remote Sensing: A Case Study in Karachi,' Remote Sensing 14, no. 7 (2022) article 1590, https://www.mdpi.com/2072-4292/14/7/1590

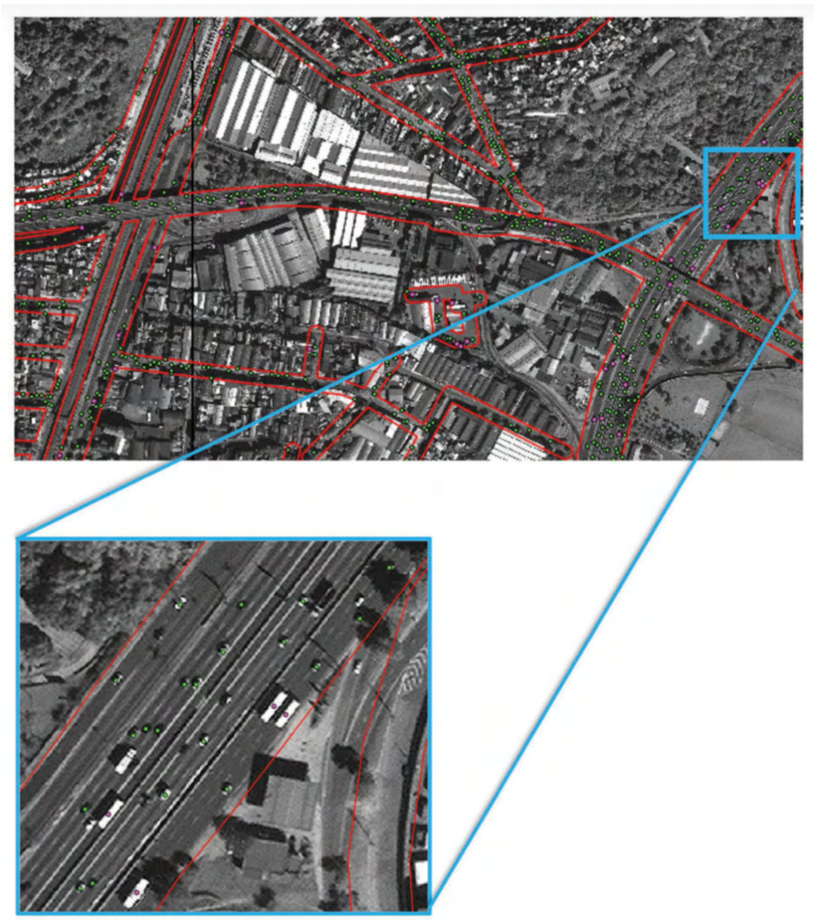
Case study 8: Assessing the impact of motor vehicle density on air pollution in Cairo

Air pollution remains a critical environmental challenge in the Greater Cairo area. Transportation is a significant contributor to Cairo's air pollution, accounting for roughly 26% of PM_{10} emissions. To address this challenge, the WB collaborated with the Egyptian Ministry of Environment through the Egyptian Environmental Affairs Agency (EEAA) to assess how the number of vehicles on the roads affects air quality. The study explored two key areas:

1. The relationship between vehicle density on Cairo's streets and the city's air quality.
2. The impacts of two recent developments on vehicle density and air quality: the inauguration and expansion of a new metro line and an increase in fuel prices.

Using machine learning (ML) algorithms trained to recognise and count vehicles in high-resolution satellite images (see Figure 17), the study counted virtually all vehicles in operation over approximately 1,000 days from 2010 to 2018.

Figure 17: Using ML and EO to Detect Cars in the Streets of Cairo on a Stretch of a Highway[54]

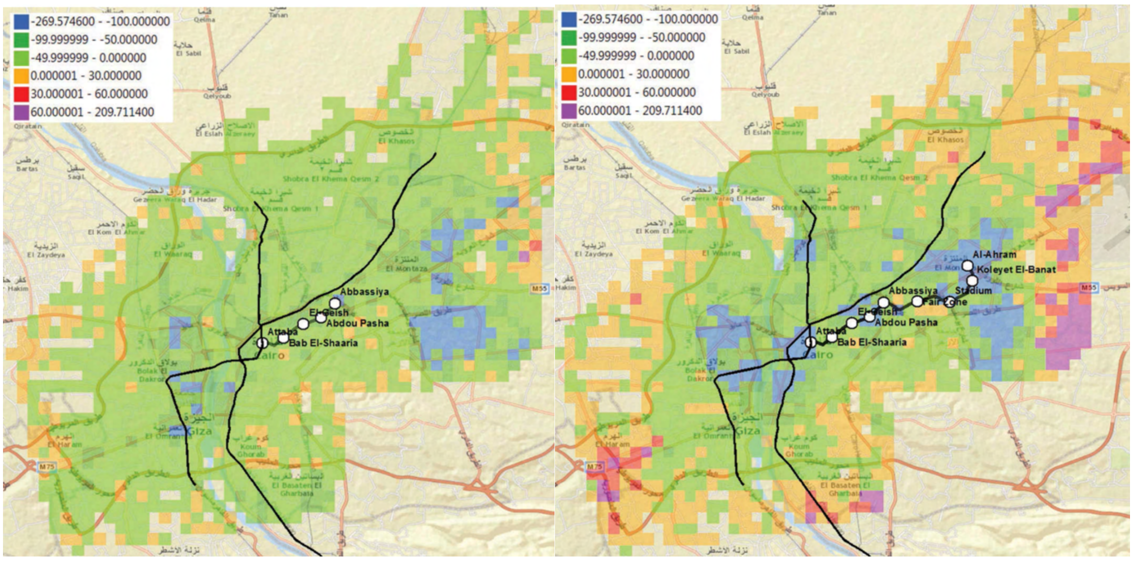


[54] M. Heger et al., Motor Vehicle Density and Air Pollution in Greater Cairo, World Bank, 2019, https://openknowledge.worldbank.org/entities/publication/78c2b3e9-4f5a-517c-be0f-f7c54aec406b

The vehicle count data was analysed alongside PM_{10} levels recorded by ground-based monitoring stations. A statistical model established a direct linear relationship between the volume of traffic and the levels of ambient air pollution. This revealed that a 1% decrease in vehicle numbers results in a 0.27% reduction in PM_{10} levels.

The study demonstrated that the opening of Cairo's new metro line resulted in a decrease in vehicle numbers across the entire region, particularly in zones that previously experienced the most severe congestion (see Figure 18a). This suggests that the metro line effectively diverted a substantial portion of road traffic to public transport. The reaction to the fuel price increase demonstrated a more complex pattern. While higher fuel prices deterred car usage in central areas, they seemingly had less influence on the outskirts (see Figure 18b), possibly due to a lack of accessible and convenient public transport options. This discrepancy suggests that while the fuel price increase contributed to reducing car numbers in congested areas, its effectiveness was limited by geographical and infrastructural factors, leading to an uneven distribution of traffic changes across the region.

Figure 18: Spatial Distribution of Car Count Changes After a) Metro Opening in 2012 (Left) and b) Fuel Price Increase in 2016[55]



By combining this analysis with the assessment of the impact of vehicles on PM_{10} reductions, the study evaluated the air quality impacts of the policy interventions in Cairo. The reduction in car counts attributed to these policies correlated with an approximate 7.3% decrease in PM_{10} levels, consistent with findings from similar national and international studies. This underscored the significant roles that macroeconomic policies, targeted pricing strategies, and public transportation developments play in shaping Cairo's air quality. Assessing the effectiveness of the two enacted policies enabled the WB to make informed policy recommendations for the development of a comprehensive Air Quality Management plan.

[55] M. Heger et al., Motor Vehicle Density and Air Pollution in Greater Cairo, World Bank, 2019, https://openknowledge.worldbank.org/entities/publication/78c2b3e9-4f5a-517c-be0f-f7c54aec406b

Current use of EO for public health in the WB and ADB

This section looks at whether and how EO products are currently being used by the WB and ADB in their public health interventions. This allows us to understand the current adoption of EO for public health, identify further opportunities for the use of EO, and recognise some of the limitations or barriers to EO adoption.

Current use of EO for public health in the WB

Currently, there are limited uses of EO for public health in the WB.[56] In the Greater Cairo Air Pollution Management and Climate Change Project, the WB supported the Government of Egypt with a US$200 million fund. However, EO was only used to count vehicles on the road, rather than to measure air pollution. Moreover, the case study focused on the impact of vehicles on the environment rather than directly on public health (see case study 8).

In contrast, the WB project "Earth Observation to Support Climate-Related Health Risk Assessment in Africa" used EO specifically to support health outcomes.[57] The project aimed to assess the effectiveness of EO in accurately identifying climatic conditions favourable for the development of disease vectors. The resulting EO Data Portal is a one-stop-shop for services and basic data-mining tools needed to explore geospatial data, particularly in the context of disease early warning systems. The portal uses Multi-sensor Evolution Analysis (MEA) technology, an advanced EO data analysis tool. Key sectors in the WB beyond Health Nutrition, and Population, such as Agriculture and Rural Development and Environment can benefit from such climate-related health risk assessments, especially in regions most affected by infectious diseases and climate change.

Current use of EO for public health in the ADB

Similarly, in the ADB there are also few examples of EO being used for public health. The Regional Malaria and Other Communicable Disease Threats Trust Fund supported projects across six domains, one of which aimed to improve information systems for malaria by:[58]

1. Testing the use of a GIS platform to address health system inefficiencies and improve health service delivery planning and management in Cambodia, Myanmar, and Vietnam.
2. Carrying out preliminary work to understand the relationship between the climate, the environment, and malaria using remote sensing satellite data.

Both the improvement of health service delivery planning and understanding the relationship between climate and infectious disease are key areas where EO could provide significant value, as previously mentioned.

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[56] Using advanced Google search; GIS OR earth observation OR satellite OR geospatial 'health' site:worldbank.org, the research team was unable to find any mention of either GIS, earth observation, satellite or geospatial in combination with health in the WB.

[57] ESA, 'Earth Observation for Sustainable Development,' 2016, https://eo4society.esa.int/wp-content/uploads/2021/11/EOSD_160905-V2-FINAL.pdf

[58] ADB, 'Regional Malaria and Other Communicable Disease Threats Trust Fund: Final Report,' 2018, https://www.adb.org/publications/malaria-trust-fund-report

Ongoing activities related to EO and public health

The European Space Agency (ESA)

At ESA, a recent increase in EO activities for public health has been observed, especially after the 2017 launch of the Copernicus Sentinel-5P mission dedicated to atmospheric measurements,[59] and following the COVID-19 pandemic. The Climate Action, Sustainability, and Science Department of ESA Earth Observation Programme Directory (EOP-S) focuses on developing products and services with various technology readiness levels, ranging from EO technologies in their concept phases to fully operationalised products and services.[60]

The ESA Φ-lab

ESA's Φ-lab mission is to accelerate the future of EO by means of transformational innovations, including exploring the use of EO satellite data and disruptive technologies (e.g., AI and ML) to benefit society through public health applications.[61] For instance, a multi-award-winning research project on forecasting dengue fever outbreaks in Brazil and Peru was conducted in partnership with UNICEF in 2022.[62]

Additionally, Φ-lab has an open research mandate; therefore, all data and ML algorithms from Φ-lab's projects are available in open source on the Artificial Intelligence for Earth Observation Portal (AI4EO).

ESA Climate Office

The ESA Climate Office is increasingly interested in exploring the nexus between health and climate change using EO satellite data. In 2020, the Climate Office published a study on the potential of an ML approach to forecast environmental cholera risk in coastal India using satellite-derived essential climate variables.[63] Through the ESA-Future Earth joint programme, the Climate Office also deploys activities to benefit public health.[64] For instance, in 2022 a pilot study advanced knowledge on the interaction between climate change, land system changes, and child health in Sub-Saharan Africa using satellite data.[65] Furthermore, a webinar held on 25 July 2023 addressed the application of remote-sensing technologies in empirical research on planetary epidemiology.[66] In 2024, the Climate Office plans to launch an activity focused on climate, health, and adaptation.

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59 ESA, 'Sentinel-5P,' 2020, https://sentinel.esa.int/web/sentinel/missions/sentinel-5p
60 ESA, 'Technology Readiness Level,' 2020, https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shaping_the_Future/Technology_Readiness_Levels_TRL
61 See ESA Artificial Intelligence for Earth Observation (ESA AI4EO) Portal, https://ai4eo.esa.int/
62 A. Sebastianelli et al., 'A reproducible ensemble machine learning approach to forecast dengue outbreaks,' Scientific Reports 14 (2024): article 3807, https://www.nature.com/articles/s41598-024-52796-9
63 A. Campbell et al., 'Cholera Risk: A Machine Learning Approach Applied to Essential Climate Variables,' International Journal of Environmental Research and Public Health 17, no. 24 (2020): article 9378, https://www.mdpi.com/1660-4601/17/24/9378
64 Future Earth, 'ESA-Future Earth joint Program,' 2020, https://futureearth.org/initiatives/funding-initiatives/esa-partnership/
65 Ibid.
66 Future Earth, 'Advancing Planetary Epidemiology through Earth Observations,' 2023, https://futureearth.org/2023/08/22/advancing-planetary-epidemiology-through-earth-observations/

EO science for society (eo4society)

Under eo4society a series of activities has been dedicated to public health since 2019 to investigate the *"untapped potential of Earth Observation for the health sector"*.[67] One of its precursor projects focused on the West Nile Virus and used satellite EO to better understand the climatic and environmental factors (e.g., water presence, soil moisture levels, vegetation density, temperature) that could cause mosquito population growth and thus the spread of the virus.[68] This project was also presented as part of a virtual workshop in 2020.[69] Consequently, a call for tender was opened in April 2023 to develop a health resilience virtual platform aiming at responding to stakeholders' needs in the field of health-related activities. The platform will integrate innovative tools including EO data, epidemiological datasets, essential climate variables, and socioeconomic models to offer key information for pandemic preparedness and risk mitigation. In January 2024, a two-day user forum called EO4Health was held in a hybrid format, aiming at *"reviewing the latest advances in the use of Earth observation technology for global health, exploring the potential offered by the existing and upcoming EO satellites together with advanced modelling, in situ data and novel technologies"*.[70]

Destination Earth

Destination Earth is a flagship initiative of the European Commission in partnership with ESA, ECMWF, and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).[71] Destination Earth is developing Digital Twin Earths (DTE), a highly accurate digital model to monitor and simulate natural phenomena, hazards, and related human activities. These DTE features are part of a large Destination Earth ecosystem, which is integrated into a groundbreaking digital platform that will support the needs of a large and diverse community of users, including citizens, scientists and academics, health practitioners, commercial entities, and policymakers. Destination Earth has a strong potential for public health applications, particularly in supporting the design of accurate and actionable human adaptation strategies and mitigation measures.

Rapid Action for Citizens with Earth Observation (RACE)

Finally, an example of a fully operational service is the RACE dashboard.[72] Initially implemented in collaboration with NASA and the Japan Aerospace Exploration Agency (JAXA), the dashboard demonstrated the use of EO data to monitor social, economic, and environmental changes during the COVID-19 pandemic.[73] It now offers user-friendly, free, and rapid access to data on different themes, including health and air quality.

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[67] Eo4society, 'Exploring the intersection between Public Health and Space,' 2023, https://eo4society.esa.int/2023/04/27/exploring-the-intersection-between-public-health-and-space/

[68] EO Science for Society, 'AI and EO as Innovative Methods for Monitoring West Nile Virus Spread (AIDEO),' 2020, https://eo4society.esa.int/projects/aideo/

[69] See more details from the workshop here: https://eo4society.esa.int/resources/eo-and-ai-for-health-and-urban-resilience/

[70] Eo4society, 'ESA EO4Health User Forum 2024' 2024, https://eo4society.esa.int/resources/esa-eo4health-user-forum-2024/

[71] Destination Earth, 'Destination Earth Service Platform' https://destination-earth.eu/destination-earth/destines-components/destination-earth-service-platform/

[72] ESA, 'Rapid Action for Citizens with Earth Observation Dashboard,' 2024, https://race.esa.int/?x=1280174.14412&y=6363954.1303&z=2.32193

[73] EO Science for Society, 'Rapid Action on Covid-19 and EO,' 2020 https://eo4society.esa.int/projects/race/

EO4HEALTH RESILIENCE

Under this Invitation to Tender (ITT), ESA is developing a health resilience virtual platform and two EO-based services.[74] These will integrate high-volume data access, processing, and information dissemination to develop innovative services and applications that meet user needs, including NGOs and stakeholders undertaking health-related activities in the field. The aim is to establish global health information services using space assets by enhancing and integrating existing monitoring and assessment frameworks in cooperation with NGOs, medical facilities, and citizens. The ITT will focus on waterborne and vector-borne infectious diseases in the context of urban green and blue areas and climate change activities. It aims to create advanced services for pandemic preparedness and risk mitigation, including predictive tools based on EO data, epidemiological datasets, Essential Climate Variables, and socio-economic models.

GDA AID Public Health

A new ITT has been announced under ESA's GDA programme, focusing on the application of EO in the field of public health.[75] This initiative marks the first exploration of the Public Health thematic sector within GDA's collaborations with IFIs. This ITT takes an agile approach of three six-month development cycles to ensure geo-information meets evolving demands and undergoes thorough testing. The ITT highlights several public health priorities and challenges that IFI teams face, including:

1. *Health infrastructure accessibility and vulnerability*
2. *Climate-related health risks*
3. *Environmentally-sensitive infectious diseases*
4. *Airborne and waterborne health hazards*
5. *Nutrition and food insecurity*

Other actors

The transboundary nature of illnesses, along with environmental and climate-related factors that worsen health conditions, means that coordination and collaboration are necessary at global, national, regional, and sub-regional levels. Sharing experiences can reduce the impact of external factors on public health and, in turn, fully leverage the value of EO for health.

The COVID-19 pandemic has accelerated and enhanced inter-institutional data-sharing within and between countries, as information systems and countries reported and shared pandemic-related data. Considering the use of EO for public health requires determining how best to share data both between government agencies and institutions at a local and national level, but also between countries to account for the trans-border nature of public health issues. Population, demographic, and socioeconomic data can be integrated with EO data on the planet's physical, chemical, and biological systems to provide targeted and actionable insights for public health authorities.

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[74] ESA, EO4HEALTH RESILIENCE, 2023 https://commercialisation.esa.int/opportunities/eo4health-resilience/
[75] ESA GDA, 'New ITT released for GDA AID Public Health,' 2023, https://gda.esa.int/2023/10/new-itt-released-for-gda-aid-public-health/

Several global organisations and initiatives foster inter-institutional data-sharing and cooperation in the use of EO data for health (see Table 2). These efforts attempt to consolidate available information on public health within central platforms and networks.

Table 2: Key Organisations Fostering Data-Sharing Globally

GEO HEALTH COMMUNITY OF PRACTICE	The **Group on Earth Observations (GEO) Health Community of Practice (CoP)** is a global network of public and private actors that uses EO data to predict and prevent heat-related health risks, infectious diseases, air quality issues, food insecurity, water-related illness, and ecosystem-related health impacts.
GEOSS Global Earth Observation System of Systems	The **Global Earth Observation System of Systems (GEOSS)** platform offers access to EO data from a variety of sources, including satellites. It connects different data sources and, in this way, increases data availability for international organisations, researchers, and public health officials.
UNITED NATIONS ESCAP Economic and Social Commission for Asia and the Pacific	**United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP)** launched several initiatives/plans: • The Geostationary Environment Monitoring Spectre in the Republic of Korea, which will enable hourly monitoring of air pollution for 20 Asian countries. • The Asia-Pacific Plan of Action in Space Applications for Sustainable Development (2018–2030) encourages data-sharing and big data analytics to contain present and future spreads of epidemics and diseases. • The Regional Space Applications Programme (RESAP) serves as a framework for collaboration and to help countries better integrate EO data into their decision-making process in all sectors, including global health.
JRC EUROPEAN COMMISSION	The **European Commission's Joint Research Centre (JRC)** published work on urban green spaces, disaster risks, wildfires, waterborne health risks, and the impacts of environment and climate. The JRC's Global Human Settlement Layer (GHSL) and Database collect data from more than 50 databases on areas such as health, air pollution, and urban greening.
GFCS GLOBAL FRAMEWORK F[illegible] CLIMATE SERVICES	The **Global Framework for Climate Services (GFCS),** implemented under the WMO, includes systematic climate observations relevant to the health sector as one of its five priorities.

Potential limitations/barriers to the increased adoption of EO for public health

Despite the recognised value of EO for public health, the current level of adoption of EO for public health in the WB, ADB, and other IFIs remains low.[76] The UN Office for Outer Space Affairs (UNOOSA) has identified several barriers that need to be overcome to achieve higher adoption rates of EO for public health.[77]

1. Access: There is limited access to high-quality EO data at the regional level.
2. Choice: Where data is available, selecting relevant data from large datasets remains challenging.
3. Framework: There is currently no international framework that facilitates the formal use of information sources by government institutions.
4. Awareness: There is low awareness of EO applications among health workers.
5. Skills: Health workers often lack space-related knowledge and skills.

After discussing these with an EO for health expert, this report identifies the following as the key barriers to the adoption of EO by IFIs for public health initiatives: **the complexities of data selection** and **a lack of political buy-in and action**.

Complexities of data selection

EO satellites provide data across a range of spatial and temporal resolutions. The choice of resolution for EO images depends on the specific health issue being addressed and the information needed. For example:

- Sea surface temperature and salinity data used to model the risk of cholera infections is available at low spatial resolution and requires daily monitoring.
- Air quality and heatwave monitoring use low-spatial resolution data, whereas high spatial resolution is needed for urban pollution.

Mosquito-borne disease risk assessment requires EO data at different levels of detail (very high to moderate spatial resolution) and at different temporal scales (from seasonal to daily data acquisition). Furthermore, the high cost of very high spatial resolution EO data is a barrier to Research & Development (R&D) in public health programmes.

Lack of political buy-in and action

Interviews conducted as part of this research showed that data availability itself is not the primary issue. Besides the fact that EO fills in gaps that ground-based stations leave behind, the bigger issue is what is being done with the information acquired. There may be improvements to be made to the use of EO to measure air quality, but the question remains as to whether ministries are

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[76] R. S. Krishnamurthy and J. Hatton, 'Space science and technologies to advance health-related sustainable development goals,' Bulletin of the World Health Organization 96, no. 1 (2018): 3–3A, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5791876/
[77] UNOOSA Committee on the Peaceful Uses of Outer Space, 'Review of responses to the set of questions on the policies, experiences and practices in the use of space science and technology for global health,' 2021, https://www.unoosa.org/documents/pdf/copuos/stsc/gh/2021/A_AC105_C1_2021_CRP7.pdf

ready to apply better data to their decision-making processes. EO data holds people accountable and includes an element of surveillance that may deter its adoption by public health officials, and funding from the WB depends on national government support. Without political buy-in, implementation fails to materialise, highlighting a disconnect between government readiness and what IFIs are willing to fund.

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