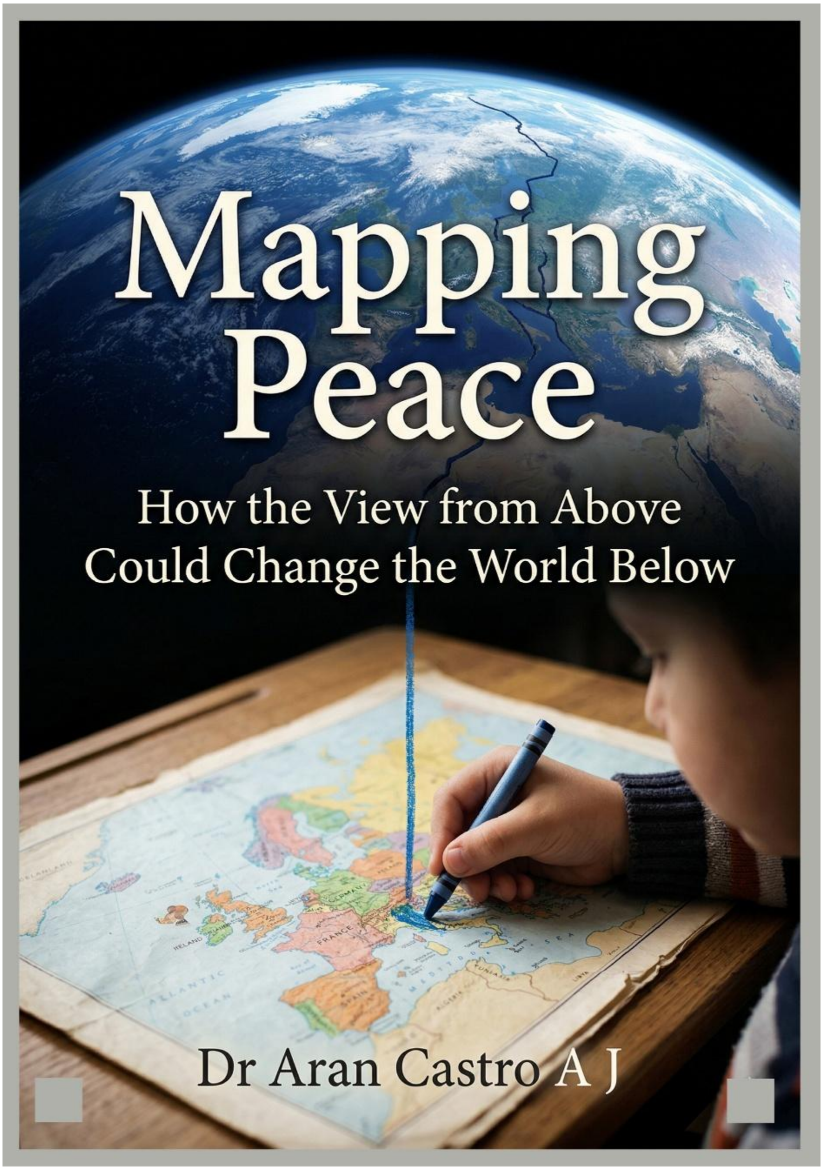

Mapping
Peace
How the View from Above
Could Change the World Below
Dr Aran Castro A J

# MAPPING PEACE

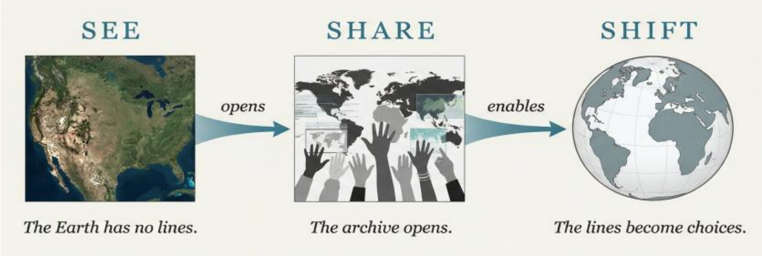
*How the View from Above Could Change the World Below*

DR ARAN
CASTRO A J

*For every child who coloured inside the lines*

*and was never told the lines were not the Earth.*

# THE ARGUMENT OF THIS BOOK




*The See/Share/Shift framework: the argumentative arc of this book.*

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# PROLOGUE

## The View from Above

The first time I saw the Earth without borders, I did not understand what I was looking at.

I was twenty-three years old, sitting in a computer laboratory at the university, and my supervisor had just opened a Landsat image on the screen. It was a composite of southern India — Tamil Nadu, Karnataka, Kerala — stitched together from data captured by a sensor orbiting seven hundred and five kilometres above the surface. I had been studying remote sensing for two years by then. I had learned the theory. I knew about electromagnetic radiation and spectral reflectance and atmospheric correction. I could recite the band combinations. But I had never, until that afternoon, actually looked at what the satellite was showing me.

What it was showing me was this: there were no lines.

The Cauvery River flowed from the Western Ghats through Karnataka and into Tamil Nadu without interruption. The vegetation gradient shifted from the dense green of the Nilgiris to the dry brown of the rain shadow in a continuous curve that followed rainfall, not jurisdiction. The coastline traced its path from Mangalore to Kanyakumari to Chennai without a single mark indicating where one state ended and another began. I knew, of course, that borders are not painted on the ground. Every schoolchild knows this in the abstract. But knowing it abstractly and seeing it — seeing an entire subcontinent rendered as one unbroken surface — are not the same experience. That afternoon, for the first time in my life, I saw the Earth as it actually is.

And the thought that entered my mind, with the quiet force of something that had been waiting a long time to be noticed, was: *If this is what the*

*Earth looks like, then why did they give us those coloured maps?*

* * *

I grew up in Tamil Nadu, a downstream state. By this I mean that the water we depend upon — for our rice paddies, our reservoirs, our drinking — originates somewhere else. The Cauvery is born in Karnataka. The Mullaperiyar Dam sits in Kerala. The decisions made upstream determine whether crops grow or fail downstream, whether taps run or stay dry, whether people eat or go hungry. I did not understand any of this as a child. What I understood was the map on the classroom wall, which showed Tamil Nadu in one colour and Karnataka in another, and from this I concluded, with the logic of a ten-year-old, that they were separate things.

In 1991, when I was still young, violence erupted in Karnataka over the Cauvery water dispute. Tamil people in Bangalore were attacked. Properties were burned. Buses were set alight. My parents spoke about it in low voices, the way adults speak when they do not want children to understand but cannot help speaking anyway. I did not fully grasp what was happening. But I grasped this much: the people on the other side of the coloured shape were angry at us, and we were angry at them, and the anger had something to do with water.

It would take me another fifteen years to understand what the satellite had been trying to tell me all along. The Cauvery basin is one hydrological system. It does not care which state legislature claims authority over which section of its channel. The rain falls on the Western Ghats; the water flows downhill; it reaches the sea. That is the physical reality. The political reality — Karnataka versus Tamil Nadu, upstream versus downstream, share versus hoard — is a reality we invented. We drew lines across a watershed and then fought each other over the water that flows through it.

This book is about those lines. Not the physical lines — rivers, ridges, coastlines — that the Earth draws on its own surface, but the political lines that human beings have drawn on top of them. It is about what happens when you have a tool — a satellite, an open archive, a shared map — that allows you to see the Earth without those lines. And it is about the question that follows, which is not a scientific question but a human one: once you have seen what the world looks like without borders, can you go on thinking about it in the same way?

* * *

I am a geospatial scientist. I work with satellite images. When people ask me what I do, I say, simply, that I work with satellite images, and they nod politely and move on to the next question, because satellite images sound technical and dull. But they are neither. A satellite image is a portrait of the Earth taken by a machine that has no nationality, no ideology, no opinion about who should own which piece of ground. It records what is there. Not what we wish were there, not what our maps say should be there, but what is actually, physically, measurably there. And what is there, consistently, across every image I have ever processed, is a planet without borders.

This is not a metaphor. I mean it literally. If you download a Landsat scene of the India-Pakistan border and display it on your screen, you will see agricultural fields, river channels, desert sand, and mountain rock. You will not see a line. The border that has produced four wars, a nuclear arms race, and seventy-seven years of mutual suspicion is, in the satellite record, invisible. It does not exist in the data. We added it afterwards, on a different layer, because we needed it to be there. The Earth did not.

The thesis of this book is simple, and I will state it plainly: *we are the only species that draws lines on the ground and then forgets we drew them.* We treat political borders as though they were natural features — as fixed as mountains, as ancient as rivers — when in fact they are recent inventions, most of them younger than the oldest living trees. And we have organised our economies, our identities, our wars, and our hatreds around these inventions with a fervour that would be impressive if it were not so destructive.

Geospatial science — the set of technologies that allows us to observe, measure, and share images of the Earth from above — is the first tool in human history that makes this forgetting difficult. When you see the world from orbit, you cannot pretend that the lines were always there. The satellite will not let you. It shows you what the Earth looks like, and what the Earth looks like is one continuous surface, shared by everyone, owned by no one.

* * *

The argument of this book moves in three stages. The first I call *See* — the act of learning to observe the Earth without the lines we have drawn on it. The satellite does not merely give us better maps; it gives us a different way of knowing the planet, one that begins with physical reality rather than political convention. The second stage I call *Share* — the revolution that occurs when the ability to see is no longer restricted to governments and militaries but becomes available to everyone. When the Landsat archive was made free in 2008, when OpenStreetMap allowed ordinary citizens to draw their own maps, when satellite imagery was admitted as evidence in international courts, the power to observe the Earth shifted from institutions to individuals. The third stage I call *Shift* — the change in thinking that becomes possible, though never inevitable, once people have seen the Earth clearly and shared that vision widely. If we can see that the world has no natural borders, and if everyone can access that vision, then the way we think about territory, sovereignty, and belonging can begin to change.

See, Share, Shift. That is the arc of this book, and I believe it is also the arc of a larger story — the story of what happens when a species that has spent ten thousand years dividing the Earth into parcels finally acquires the means to see what it has been dividing.

* * *

I need to say one more thing before we begin. I did not write this book because I believe that borders should be abolished. That is not my argument, and anyone who reads it that way has misread it. Borders serve functions. They organise governance, distribute resources, define legal jurisdictions. I carry an Indian passport and I am proud of it. The question I am raising is not whether borders should exist but whether we should mistake them for the Earth itself. There is a difference between drawing a line because it is useful and believing the line was always there. The first is administration. The second is a kind of forgetting that has cost millions of lives.

I wrote this book because I am a scientist who has spent his career looking at the Earth from above, and what I have seen has changed me. I cannot look at a political map the same way I did when I was ten years old. The coloured shapes no longer seem innocent. And I believe — with the urgency that comes from watching the same mistakes repeated across continents and centuries — that if more people could see what the satellite shows, they too would find it harder to forget that the lines are ours.

The Earth has no borders. We drew them. This is a book about what happens when we finally see that clearly.

PART ONE

# SEE

*Learning to Observe the Earth Without the Lines We Drew*

CHAPTER ONE

# The Coloured Shapes

When I was a boy in school, they gave us empty maps. Blank outlines of the subcontinent, photocopied and slightly crooked, with nothing inside except the faint grey tracery of state boundaries. Our job was to fill them in. Mark the capital cities. Label the rivers. Shade the states in different colours so that no two neighbours shared the same hue. It was, I suppose, a geography lesson. But I did not experience it as geography. I experienced it as colouring.

India was always pride for me. That is not a political statement; it is the simple truth of what a child feels when he is taught that his country contains more languages than most continents, more faiths than most civilisations, and yet remains

— against all reasonable expectation — one nation. The map confirmed this. There it was: a single shape, broad at the top, tapering to a point at Kanyakumari, cradling Sri Lanka like a parent watching over a child who has moved out but not far. I coloured it in. I wrote the names. I drew a small star where Delhi sat. And I believed, with the absolute certainty that only a ten-year-old can muster, that I understood what a country was.

I also believed — and this is the part that matters — that neighbours were friends. My reasoning was simple and, I think, not stupid. My neighbour was my friend. We shared a wall. We borrowed sugar. Our mothers complained about the same water pressure. So when I looked at the map and saw that Pakistan sat right next to India, coloured in a different shade but pressed against the same border, I assumed the relationship was similar. They were our neighbours. Surely they were our friends.

I grew up.

I learned that not all neighbours are friends. That India and Pakistan have fought four wars over territory that looks, from the air, like the same brown mountains continuing across an imaginary line. That North Korea and South Korea share a peninsula, a language, a cuisine, thousands of years of common ancestry, and a border so militarised that satellites can photograph it at night as a sharp line between light and darkness. I learned that the Israelis and Palestinians live on the same land, drink from the same aquifer, suffer under the same sun, and have spent three-quarters of a century arguing about which colour that land should be on the map.

The coloured shapes had lied to me. Or rather — and this is the distinction that would take me another fifteen years to articulate — the coloured shapes had taught me to see the world in a way that made the lying invisible.

* * *

Consider the political map. Not any particular political map — the form itself. You know it before I describe it. You have seen it on classroom walls, in airline magazines, on the nightly news whenever a correspondent stands in front of a screen to explain why some part of the world is, once again, in trouble. It is the map that divides the Earth's land surface into coloured shapes, each representing a sovereign state, each separated from its neighbours by a line that appears as solid and permanent as a coastline.

This map is so familiar that it requires a deliberate act of estrangement to see it for what it is. It is not a representation of the Earth. It is a representation of a theory about the Earth — a theory that says the most important fact about any piece of land is which government claims authority over it. The political map does not show you the soil. It does not show you the watershed, the vegetation, the temperature gradient, the animal migration routes, the trade networks, the shared aquifers, the continuous forests, the river systems that flow serenely across the borders we have drawn through them. It shows you, instead, a world made entirely of sovereignty. As if sovereignty were a physical property of the ground, like calcium content or elevation.

It is not. Sovereignty is a human invention, and a remarkably recent one. The Treaty of Westphalia, signed in 1648 to end the Thirty Years' War in Europe, is conventionally cited as the origin of the modern state system — the idea that the world is properly divided into territories, each governed by a single sovereign authority, each recognising the others' right to exist within their own boundaries. Before Westphalia, the political organisation of human societies was a far messier affair: overlapping jurisdictions, feudal obligations that crossed what we would now call borders, religious authorities that claimed dominion over souls regardless of geography, empires that thought of their edges not as lines but as gradients of declining influence.

The Westphalian system changed this. Slowly, unevenly, and with tremendous violence, the world was reorganised into bounded territories. And the political map became the standard way of depicting this reorganisation — a way so effective that, within a few generations, people stopped seeing it as a depiction at all. They started seeing it as the thing itself. The map became the territory, to invert Korzybski's famous warning. Or more precisely: the map's way of organising reality became so naturalised that it stopped being visible as an organisation. It became, simply, *the way the world is*.

I call this *territorial thinking*. It is the habit of mind that treats political boundaries as if they were natural features of the Earth — as permanent as mountain ranges, as inevitable as the course of a river. Territorial thinking is what allows a person to look at a map of Kashmir and see an Indian region, or a Pakistani one, or a disputed one, depending on where the map was printed, without ever asking the prior question: what does the land itself look like when nobody is arguing about who owns it?

* * *

Maps, of course, existed long before Westphalia. Humans have been drawing representations of their surroundings for at least fourteen thousand years, since someone in a cave in what is now Navarra, Spain, scratched a recognisable landscape onto a flat stone. But the political map — the map whose primary purpose is to show which sovereign entity controls which territory — is a product of a specific historical moment, and that moment is European colonialism.

The great cartographic projects of the eighteenth and nineteenth centuries were not exercises in disinterested science. The Survey of India, begun under the East India Company in 1767 and continued by the British Raj, was among the largest scientific undertakings of its era. It produced maps of extraordinary precision. It triangulated the subcontinent. It measured the height of Everest. And it did all of this in the service of administration and control. To map a territory was to claim it. The map was simultaneously a description of what existed and a prescription for what was permitted. Every line drawn on paper was, implicitly, a line drawn on the ground — a line that told people where they could go, what they could do, whom they owed allegiance to.

When the British left India in 1947, they left behind many things: a railway network, a bureaucratic tradition, a language that would become the medium of instruction in most universities, and a border. The Radcliffe Line, drawn by a London barrister named Cyril Radcliffe who had never visited India, divided the subcontinent into two nations in a matter of weeks. Radcliffe worked from outdated census data and inadequate maps. He had no knowledge of the local geography, no understanding of the irrigation systems that crossed his line, no awareness that he was cutting through villages whose residents had never thought of themselves as belonging to different countries. He was, in the most literal sense, colouring in a map. And the colours he chose — India in one shade, Pakistan in another — would determine the fates of millions.

Between twelve and twenty million people were displaced. Between one and two million died. Families that had lived together for generations found themselves on different sides of a line that had not existed six months earlier. And the line persisted. It hardened. It acquired fences, and soldiers, and minefields. It became, in the language of territorial thinking, a *border* — as if it had always been there, as if the land itself had demanded it.

I think about Cyril Radcliffe often. Not with anger — anger is too simple for what he represents. I think about him with a kind of scientific sadness. Here was a man given a map, a pencil, and a deadline. He did not walk the land. He did not study the watersheds. He did not ask the rivers where they went or the farmers where they drew their water. He sat in a room in Lahore and drew a line, and the line became the truth. The map made the world, instead of the other way around.

* * *

Years later — many years after the school maps, after the discovery that neighbours are not always friends, after the slow accumulation of a scientist's education — I opened Google Earth for the first time. I do not remember the exact year. I remember the feeling. I zoomed into the Indian subcontinent, expecting to see the shape I knew, the shape I had coloured in as a child, the shape that meant pride and unity and home. And what I saw instead was the Earth.

Brown mountains in the north, fading into the pale white of glaciers. Green river plains stretching south and east, the Ganges and its tributaries visible as dark threads winding through agriculture. The Thar Desert bleeding into the Indus Valley without apology or interruption. And no lines.

No borders. No coloured shapes. The land did not know where India ended and Pakistan began. The Himalayas did not pause at a checkpoint. The monsoon did not stop at the Line of Control.

In India, the map looks one way. From Pakistan, it looks different. From China, different again. Three countries, three maps, three versions of where the borders fall in Kashmir and Aksai Chin and Arunachal Pradesh. In each country, children fill in the shapes they are given, just as I did. They colour their nation in one colour and the neighbours in another. They learn, without anyone explicitly teaching them, that the world is made of these shapes. That the shapes are real.

But from space, it is one.

That sentence is the simplest thing I know, and it has taken me my entire career to understand what it means. From space, the Indian subcontinent is a single geological entity — a tectonic plate that crashed into Asia fifty million years ago, raising the Himalayas in the collision, creating a landmass whose rivers, weather systems, and ecosystems operate as a continuous whole regardless of the lines drawn across them in 1947. The water that falls as snow in the Karakoram does not check its passport before flowing into the Indus. The dust that rises from Rajasthan drifts into Sindh without a visa. The aquifer beneath the Punjab — the *whole* Punjab, Indian and Pakistani — is a single body of water being drawn down by farmers on both sides who will never meet each other but who are, in the most material sense, drinking from the same well.

Geospatial science did not teach me this as a fact. Facts I already had. Every geography textbook will tell you that rivers cross borders and weather systems ignore sovereignty. What geospatial science taught me was something more uncomfortable: it taught me to *see* it. To look at the Earth from above and experience the absence of borders not as an abstraction but as a visual reality. The satellite image is not a map. It does not interpret. It does not assign colours to countries or draw lines where governments claim jurisdiction. It simply records what is there. And what is there, always and everywhere, is a world that has not heard of the Westphalian system.

* * *

I want this book to restore a sense of strangeness to the political map. I want you, the reader, to look at those coloured shapes and feel, if only for a moment, the oddness that I felt when I first compared my school atlas with a satellite image. Here is a species that has existed for roughly three hundred thousand years. For all but the last four hundred of those years, it organised itself in ways that bore almost no resemblance to the current system of sovereign nation-states. And yet we treat that system — with its rigid boundaries, its passport controls, its coloured shapes — as if it were as natural as gravity.

It is not natural. It is technology. The political map is a technology for organising human life on the surface of the Earth, and like all technologies, it has costs and benefits, and like all technologies, it becomes dangerous when people forget that it was invented. The danger of territorial thinking is not that it is wrong — boundaries serve real purposes. The danger is that it is *invisible*. We do not see it as a way of thinking. We see it as the way things are.

Geospatial science — the science of observing the Earth from above, of measuring it with satellites and sensors and algorithms — offers something that no previous technology has offered: a way of seeing the Earth that does not begin with the assumption that it is divided. When a Landsat satellite passes over the India-Pakistan border, it records the same spectral bands on both sides. The vegetation index does not change at the Line of Control. The land surface temperature is continuous. The data does not know about partition.

This is not a political argument. It is an empirical observation. And it is the starting point of everything this book has to say. We have built a civilisation on coloured shapes, and we have done so with such thoroughness that most of us cannot imagine the world without them. But there is now a tool — a set of instruments, a scientific discipline, a way of looking — that lets us see what the Earth actually looks like underneath the colours we have painted on it. What it looks like is continuous. What it looks like is connected. What it looks like is a single planet that does not know it has been divided.

The child who coloured in that map was not wrong to think that neighbours should be friends. He was wrong about the mechanism. It is not proximity that makes friendship. It is the ability to see each other clearly. And that, as it turns out, is something a machine in orbit can help with — if we are willing to look at what it shows us.

CHAPTER TWO

# The Eye That Does Not Blink

The first time I loaded a Landsat image into my software, I expected to see the Earth. What I saw instead was a spreadsheet. Rows and columns of numbers, each cell containing a value between zero and several thousand, representing the amount of electromagnetic energy reflected from a thirty-metre patch of the planet's surface. No colour. No shape I recognised. No resemblance whatsoever to the blue marble I had seen in photographs since childhood. Just numbers. Thousands upon thousands of numbers, arranged in a grid that meant nothing to my eyes until I learned how to ask the right questions of it.

This is the first thing that nobody tells you about satellite remote sensing: the satellite does not take photographs. A photograph captures what the human eye would see if it were floating at that altitude — the visible spectrum, the narrow band of electromagnetic radiation between roughly 400 and 700 nanometres that our retinas happen to be equipped to detect. A satellite sensor does something fundamentally different. It measures energy across multiple bands of the electromagnetic spectrum, including wavelengths that no human eye has ever seen or will ever see. Near-infrared. Shortwave infrared. Thermal infrared. Each band is recorded separately, as its own grid of numbers, and it is only when a human being sits down at a computer and assigns colours to those bands — red to one, green to another, blue to a third — that an image appears on the screen.

The image, in other words, is a translation. It is a decision. Someone chose which bands to display and which colours to assign to them, and that choice determines what you see. Display bands 4, 3, and 2 of a Landsat 8 image as red, green, and blue, and you get something that looks approximately like a photograph — a “true colour” composite, familiar and legible, water blue and vegetation green and cities grey. But display bands 5, 4, and 3 instead, and the world transforms. Vegetation blazes red — a deep, arterial crimson that makes healthy forests look like they are on fire and stressed crops look pale and sickly. Water goes black. Bare soil turns grey-brown. The Earth becomes an alien planet, gorgeous and unsettling, and every colour in it is a piece of information that your naked eye could never have gathered.

I was astonished, in those early days, by a simple fact that I still find remarkable: you can derive an urban heat island map and a vegetation health index from the same image. The same satellite pass, the same moment in time, the same grid of numbers — but by choosing different bands and different calculations, you can make the data reveal entirely different truths about the same piece of ground. Band 10 shows you the thermal radiation the surface is emitting, and from it you can map which parts of a city are dangerously hot and which are cooled by tree cover. Bands 5 and 4, combined in a simple ratio called the Normalised Difference Vegetation Index, show you where plants are photosynthesising and where they are dying. One image. Two invisible realities, neither of which a person standing on the ground could perceive without instruments.

I thought about this for days. How the bands can differ so vastly, and yet they all describe the same place at the same time. It was as though someone had handed me a book written in seven languages simultaneously, each language describing a different aspect of the same story, and told me that the story could not be understood in any single language alone. You had to read them all. You had to learn to move between them. The Earth was not one image. It was seven. Or twelve. Or, with hyperspectral sensors, two hundred and forty-two. And each one showed you something the others did not.

* * *

The Landsat programme began with a launch from Vandenberg Air Force Base in California on 23 July 1972. The satellite was called ERTS-1 — Earth Resources Technology Satellite — and it carried a multispectral scanner that could image the planet's surface in four spectral bands at a resolution of roughly eighty metres. It was not the first satellite to photograph the Earth; weather satellites and spy satellites had been doing that since the early 1960s. But it was the first satellite designed specifically to observe the land surface of the planet on a repeated, systematic basis, for scientific and civilian purposes.

The scientists who designed ERTS-1 understood something that the broader public would take decades to grasp: that the value of a satellite is not in any single image but in the repetition. A photograph of a forest taken once is a curiosity. A photograph of the same forest taken every sixteen days, year after year, decade after decade, is a record of change. It is a memory that the Earth itself does not possess — a record of what was there before the clearing, before the drought, before the dam, before the fire, before the city spread into the farmland. The satellite does not blink. It passes over the same ground on the same schedule, recording the same measurements, and the archive it builds is a kind of planetary autobiography written in reflected light.

Landsat is now in its ninth generation. The programme has been acquiring data continuously for over fifty years, making it the longest unbroken record of the Earth's land surface in existence. More than ten million scenes sit in the archive. And since 2008 — a moment I will return to in a later chapter — that entire archive has been free. Anyone with an internet connection can download a Landsat image of any place on Earth, from any date in the last half-century, and look at what was there. This is, if you pause to think about it, an extraordinary thing. It means that deforestation in the Amazon can be tracked by a student in Mumbai. That the shrinking of the Aral Sea can be measured by a researcher in Nairobi. That the expansion of cities, the retreat of glaciers, the flooding of rivers, and the burning of savannahs are all documented, automatically and impartially, by an instrument that does not care who owns the land it is observing.

I say “impartially” with care. The satellite does not know about borders. It does not adjust its orbit to respect sovereignty. When Landsat 8 passes over the Indian subcontinent, it records data for India, Pakistan, Bangladesh, Nepal, Bhutan, and Sri Lanka in a single continuous swath. The data does not pause at the Line of Control. The pixels on one side of the India-Pakistan border are recorded with exactly the same instrument, at exactly the same resolution, in exactly the same spectral bands, as the pixels on the other side. Whatever territorial thinking has done to the ground — whatever fences have been erected, whatever minefields have been laid, whatever hostile architecture has been built to enforce the idea that this side and that side are fundamentally different — the sensor does not see it. The sensor sees reflectance. And reflectance does not have a nationality.

* * *

There is a concept in the philosophy of science called an *epistemic instrument* — a tool that does not merely measure something we already know about but changes what it is possible to know. The telescope was such an instrument. Before Galileo pointed his at Jupiter, the moons of Jupiter were not merely undiscovered; they were unimaginable within the prevailing model of the cosmos. The microscope was another. Before van Leeuwenhoek, the existence of microorganisms was not a hypothesis waiting to be confirmed; it was not even a question anyone knew to ask. The instrument created the knowledge by creating the possibility of observation.

I want to argue that the Earth observation satellite belongs in this category. It is not simply a better way of mapping the planet. It is a different way of knowing the planet. And the difference matters because it changes what questions we are able to ask.

Consider a concrete example. Before satellites, if you wanted to know whether a river was polluted, you went to the river. You collected water samples. You brought them back to a laboratory and analysed them. This is still done, and it is still necessary, but it has obvious limitations: you can only sample where you can physically go, and you can only sample at the moments you are there. A satellite equipped with the right sensors can estimate chlorophyll concentration, turbidity, and suspended sediment load across an entire river basin, simultaneously, every few days. It cannot replace ground sampling, but it can tell you where to sample — and more importantly, it can show you patterns that no number of ground visits could reveal, because the patterns only become visible from above.

Or consider deforestation. A forester walking through a forest can see the trees in front of him. He can hear the chainsaws if they are near enough. But he cannot see the shape of the clearing, because the shape is only legible from orbit. He cannot see that the clearing follows a road that was built six months ago, that the road connects to a larger road that was built two years ago, that the pattern of roads is the signature of a specific kind of illegal logging operation that has been documented in three other regions. The satellite sees all of this at once. It sees the pattern, not just the instance. And the pattern is where the understanding lies.

This is what I mean when I say that the satellite is an epistemic instrument. It does not just show you more of what you already knew. It shows you things that could not be known without it — things that are, by their nature, invisible from the ground. The shape of a city's heat distribution. The rate at which a glacier is retreating compared to its neighbours. The correlation between vegetation health on one side of a border and agricultural policy on the other. The fact that the Indus River basin is a single hydrological system being managed as if it were two. These are not opinions. They are measurements. And they are measurements that were impossible before the eye in the sky began to look.

* * *

I work with satellite images. That is what I tell people when they ask what I do. I say it simply because the truth is simple, even if the work is not. I sit in front of a screen. I load images. I process bands. I run algorithms. I write code that tells a computer how to read the numbers that a satellite recorded, and I interpret what the computer finds. Most days, this is routine. The data arrives. I process it. I write up the results. The wonder, if I am honest, faded some years ago — not because the data became less remarkable, but because familiarity does what it always does. The thousandth false-colour composite looks less alien than the first.

And then, one evening, I was sitting on my sofa watching the news, and the news was showing satellite images.

They were before-and-after images. The "before" showed buildings, roads, a military installation — the familiar geometry of human settlement rendered in the familiar grey tones of high-resolution commercial imagery. The "after" showed rubble. Craters. The precise, geometric signatures of targeted destruction. The news anchor was explaining the images as evidence — proof of what had been hit, what had been destroyed, what had changed between one satellite pass and the next. The images were of Pakistan, taken after the strikes of Operation Sindoor.

I sat there and watched my own science being used on television to narrate a military operation. The bands I work with every day. The resolution I can estimate at a glance. The spectral signatures I have spent years learning to read. All of it, on a screen in my living room, being used not to study vegetation health or urban heat islands or water quality, but to show what one country had done to another. To show destruction. To show, with the clinical precision that only a satellite can provide, exactly what had been broken and where.

I do not know how to describe what I felt except to say that it was the opposite of routine. It was the feeling of recognising your own language being spoken in a context you never expected. The satellite does not choose what it observes. It passes over everything. It records the forest fire and the forest. The city expanding and the city bombed. The river flowing and the river dammed. The eye does not blink, and it does not look away, and it does not distinguish between the things we want to see and the things we would rather not know about.

That impartiality is the satellite's greatest scientific virtue and its most unsettling moral quality. The same instrument that helps me map drought-stressed crops in Rajasthan can be used to assess bomb damage in Balochistan. The same Landsat band that reveals the health of a mangrove forest can reveal the footprint of a military camp. The data is the data. What we do with it is the question, and it is a question that the satellite cannot answer for us.

I need to be honest about what this means for the argument of this book. Earth observation technology does not merely empower scientists and humanitarian organisations. It empowers states. The Cartosat-3 satellite that photographs Punjab without seeing the border also serves India's defence intelligence requirements. The same sub-metre resolution that lets a geomorphologist study the Brahmaputra's channel migration lets a military planner assess infrastructure on the other side of the Line of Control. Remote sensing data is used for border surveillance, refugee tracking, counter-insurgency planning, and the monitoring of populations that governments wish to control. The history of Earth observation is, in part, a history of military development — the first reconnaissance satellites were classified, and the civilian programmes that followed them inherited both their technology and, in some cases, their logic. The same archive that I celebrate as a resource for open science is also a resource for the surveillance state. Any honest account of what satellite imagery can do must acknowledge both uses. The eye that does not blink sees everything, and not everything it sees is seen in freedom's service.

* * *

This chapter has been about a machine. A sensor mounted on a platform, launched into orbit, circling the Earth every ninety-nine minutes, recording reflected electromagnetic energy in multiple spectral bands. It is not intelligent. It does not think. It does not care. It is, in the most literal sense, an eye that does not blink.

But what this machine has done to human knowledge is not mechanical. It has given us a perspective we never had — a view of our own planet that is continuous where our politics are fragmented, that is repeated where our attention is sporadic, that is multispectral where our vision is limited to a thin sliver of the electromagnetic spectrum. For fifty years, the satellite archive has been accumulating a record of the Earth's surface that no library, no census, no diplomatic correspondence could match for completeness and dispassion.

When I was a child, I coloured in maps and thought I understood the world. When I was a student, I loaded my first Landsat image and realised I did not. The coloured shapes of the political map had given me a world divided into neat, sovereign parcels. The satellite gave me a world that was continuous, connected, and indifferent to the boundaries I had been taught to see. Both of these are representations. Neither is the Earth itself. But one of them — the one built from measurements rather than claims — is closer to what is actually there.

The eye does not blink. The archive grows. And every sixteen days, when Landsat passes over the same ground again, it asks the same question it has been asking since 1972: *What is here now?* Not *whose is it*. Not *what should be done about it*. Just: *what is here*. It is the simplest question a scientist can ask, and it is the question that territorial thinking has spent four centuries training us not to hear.

CHAPTER THREE

# The River Does Not Know

The Cauvery rises in the Brahmagiri Hills of Coorg, in the state of Karnataka. It begins as a small spring at Talakaveri, a temple site surrounded by evergreen forest, where priests perform rituals at the exact spot where the water emerges from the earth. From there it flows south-east through the Deccan plateau, gathering tributaries — the Harangi, the Hemavati, the Kabini — swelling into a wide, slow river that irrigates some of the most productive farmland in southern India. It passes through Mysore. It enters Tamil Nadu at a place called Hogenakal, where the river drops over a series of waterfalls and the state boundary crosses it like a line drawn through a sentence that is not yet finished. From Hogenakal it flows east through the Mettur reservoir, through the rice country of the

Thanjavur delta, and finally empties into the Bay of Bengal at Poompuhar.

The river does not know any of this. It does not know that it rises in Karnataka and dies in Tamil Nadu. It does not know that it crosses a state boundary at Hogenakal, that the water on one side of that boundary is the subject of a Supreme Court verdict and the water on the other side is the subject of a different Supreme Court verdict, and that the difference between the two has, on at least two occasions in living memory, led to people being beaten in the streets.

I am from Tamil Nadu. This is not a disclosure I make lightly in the context of the Cauvery dispute, because in southern India, saying where you are from in a water argument is like declaring which army you belong to. But I say it because it matters for what follows. I grew up downstream. The water that reached my state had already passed through another state's politics, another state's dams, another state's farmers' fields. And when the water did not come — when the rains failed, or the reservoir was not released, or the courts were still deliberating — it was not an abstraction. The paddy fields dried. The delta farmers, who had built their entire way of life around the assumption that the Cauvery would flow, watched their crops fail and did the arithmetic of ruin.

In December 1991, after the Cauvery Water Disputes Tribunal issued an interim order directing Karnataka to release water to Tamil Nadu, riots broke out in Bangalore and Mysore. Tamil-owned businesses were burned. Tamil-language cinema halls were attacked. Vehicles bearing Tamil Nadu registration plates were set on fire. Thousands of Tamils fled southern Karnataka in a matter of weeks, driven out of cities where some of them had lived for decades. In 2016, it happened again — arson across Bengaluru, a curfew imposed, two people dead — all because a court had ordered one state to share water with another.

I remember being a student and struggling to understand how water — water, which falls from the sky, which flows downhill, which has been doing these things for several hundred million years — could make neighbours into enemies. Not India and Pakistan this time. Not two countries separated by history and religion and nuclear weapons. Two states within the same country. Two states that share a language family, a cuisine, a film industry, a cricket team. Two states that could not agree on how to share a river, because the river belonged to neither of them and both of them at once, and the political architecture of the modern state had no way of expressing that fact.

* * *

Here is something that most people outside Tamil Nadu do not know, and that most people inside Tamil Nadu feel in their bones: almost none of Tamil Nadu's major rivers originate within its borders. The Cauvery rises in Karnataka. The Bhavani, one of the

Cauvery's chief tributaries, begins in the Silent Valley of Kerala. The Palar and the Ponnaiyar start in the Nandi Hills of Karnataka. The Vaigai, which waters Madurai, depends on the Periyar dam — a structure built across a river in Kerala, diverting water eastward through a tunnel in the Western Ghats into the rain shadow on the Tamil Nadu side.

Tamil Nadu is, in hydrological terms, a downstream state. Its water arrives from elsewhere. This is not a failure of planning or a quirk of geography that might have been otherwise. It is the consequence of a simple physical fact: the Western Ghats run along the western edge of the peninsula like a wall, catching the southwest monsoon on the Kerala side and leaving Tamil Nadu in a partial rain shadow. The northeast monsoon brings some relief, but the state's agriculture, its cities, its forty million farmers — all of them depend, to a degree that would alarm any risk analyst, on water that crosses a political boundary before it reaches them.

Now look at this situation from above. Open a satellite image of peninsular India — not the political map with its clean state boundaries in different colours, but an actual Landsat composite, bands 5, 4, 3, vegetation glowing red in the false-colour rendering. What you see is a single watershed system. The Western Ghats form a ridge. Water that falls on the eastern slope flows east, through Karnataka and Tamil Nadu, into the Bay of Bengal. Water that falls on the western slope flows west, through Kerala, into the Arabian Sea. The vegetation is continuous. The topography is continuous. The soil moisture gradient runs from wet in the west to dry in the east without interruption. Nowhere in this image is there a line that says: the water belongs to Karnataka until this point, and to Tamil Nadu after it.

The satellite sees a basin. The law sees two states. And the people who live in the basin see either injustice or entitlement, depending on which side of the line they were born on. This is territorial thinking applied to hydrology, and it is, I would argue, one of the clearest demonstrations of why the habit of dividing continuous systems along political boundaries produces not just bad policy but actual violence.

* * *

If the Cauvery dispute is the most famous water conflict in southern India, the Mullaperiyar is the most absurd. The Mullaperiyar Dam was built in 1895 by the British, across the Periyar River in what is now Kerala, for the specific purpose of diverting water eastward to the drought-prone districts of what is now Tamil Nadu. The dam is now 131 years old. It is built of limestone and surkhi — a mortar made from brick dust — and it holds back a reservoir that sits, in Kerala's view, like a loaded weapon above the heads of 3.5 million people living downstream in the Idukki and Ernakulam districts.

Kerala wants a new dam. Tamil Nadu wants the old dam raised. Kerala says the old dam is unsafe. Tamil Nadu says Kerala's safety concerns are a pretext for reducing the water supply. The

Supreme Court has ruled. Expert committees have assessed. Engineers have inspected. And the argument continues, because the argument is not really about engineering. It is about the fact that a river in one state has been diverted to feed the fields of another state, and the political framework through which both states understand their rights has no vocabulary for describing a shared resource that does not belong to either.

Load a digital elevation model of the Western Ghats in this region. Drape a satellite image over the terrain. What you see is a mountain wall with a notch in it — the Periyar valley, cutting through the Ghats, creating a natural passage between the wet side and the dry side. The British engineers who built the dam in 1895 did not invent this passage. They exploited a geological fact that had existed for millions of years: that the Western Ghats are not an unbroken wall, that there are gaps and valleys and low points where water, if redirected, can flow from abundance to scarcity. The dam simply formalised what the landscape already suggested. But the politics surrounding the dam treat it as though Tamil Nadu stole Kerala's water, or as though Kerala is withholding Tamil Nadu's birthright, because the political map insists that the water must belong to one or the other.

The water belongs to gravity — a statement about physics, not about politics. Water flows downhill. It follows the gradient of the terrain, not the gradient of sovereignty. And any system for managing water that begins by assigning ownership to a political entity rather than by describing the physical behaviour of the watershed will, inevitably, produce conflict. Not because people are unreasonable, but because the framework is asking the wrong question. It asks: whose water is this? The water does not know whose it is.

* * *

What is true of the Cauvery and the Periyar within India is true, at a larger scale, of every transboundary river on the planet. The Nile, which flows through eleven countries and sustains over three hundred million people, is perhaps the most consequential example. Egypt, which sits at the river's mouth, has claimed a "historic right" to the Nile's waters since a 1929 treaty signed under British colonial auspices — a treaty that gave Egypt the right to veto any upstream project that might reduce the flow. Ethiopia, where approximately eighty-five per cent of the Nile's water originates in the Blue Nile, was not a party to that treaty and does not recognise it.

Since 2011, Ethiopia has been building the Grand Ethiopian Renaissance Dam on the Blue Nile — a structure that, when completed, will be the largest hydroelectric dam in Africa. Egypt views the dam as an existential threat. Ethiopia views it as a sovereign right. Sudan, caught between the two, has oscillated between support and anxiety. Negotiations have stalled, restarted, and stalled again. The language of the dispute is the language of territorial thinking: my water, your dam, our rights, their aggression.

And yet, if you load a MODIS composite of the Nile Basin during the wet season, what you see is a single hydrological system that operates according to a logic that has nothing to do with the arguments being made about it. Rain falls on the Ethiopian Highlands. It collects in Lake Tana. It flows north through Sudan, joining the White Nile at Khartoum. It continues through the Sahara — a river flowing through a desert, one of the more remarkable facts in physical geography — and reaches Egypt, where it fans into the delta and empties into the Mediterranean. The satellite image shows you this entire system in a single frame. The water that Ethiopia dams and the water that Egypt drinks are the same water. Not metaphorically. Physically. Molecularly. The same $H_2O$.

When I look at satellite imagery of the Nile Basin, I do not see three countries in a dispute. I see a river system behaving exactly as river systems behave — collecting water from high ground, transporting it to low ground, depositing sediment, building deltas, sustaining ecosystems and agriculture along the way. The borders drawn across this system are like lines drawn across a circulatory system: you can draw them, but the blood does not stop flowing. And any policy that treats the Nile as though it were three separate rivers belonging to three separate countries is describing a fiction, however legally established that fiction may be.

* * *

States exist. Treaties exist. The Cauvery Water Disputes Tribunal exists, and its verdicts, however imperfect, have prevented worse outcomes than the ones we have seen. The argument here is narrower and, I think, harder to dismiss: that the way we *see* water determines how we fight about it, and that the political map forces us to see water as a series of national or state-level entitlements rather than as a physical system that connects people whether they want to be connected or not.

Geospatial science offers a different starting point. When a satellite observes a river basin, it does not begin with jurisdiction. It begins with measurement. How much water is there? Where is it flowing? How fast is the reservoir filling? What is the soil moisture in the downstream agricultural zone? Is the vegetation healthier on one side of the border than the other, and if so, why? These are empirical questions, and they can be answered with data that both sides of a dispute can see, because the satellite does not take sides. It does not produce an Indian map of the Cauvery or a Pakistani map of the Indus. It produces a map of the water.

This is the "See" in my framework — the first step in a process that I believe can change how we manage shared resources. Before you can share a river, you have to see the river as it actually is: not as a line on a political map that changes colour at a boundary, but as a continuous physical system whose behaviour can be measured, modelled, and predicted. The satellite provides this seeing. It provides the common image — the one picture of the basin that does not depend on which government produced it, because it was produced by a machine in orbit that does not know what a government is.

I think about the farmers in the Thanjavur delta, whose paddy fields depend on the Cauvery's flow, and the farmers in the Mandya district of Karnataka, whose sugarcane and rice depend on the same water before it crosses the border. If you showed both groups the same satellite image of the basin — the same false-colour composite showing soil moisture, crop health, reservoir levels — they would see the same thing. They would see that their fields are part of the same system. That the water feeding the sugarcane in Mandya and the paddy in Thanjavur fell from the same clouds, collected in the same catchment, flowed through the same channel. The satellite would not tell them how to divide the water. But it would show them, with a clarity that no political map has ever provided, that they are dividing a single thing.

The river does not know that it crosses a boundary. But the people who depend on it might learn to see what the river sees — if they are given the right instrument. That instrument exists. It has been orbiting for fifty years. And the data it collects is, as of 2008, free for anyone to download. The question is not whether we can see the river as one system. The question is whether we are willing to.

PART TWO

# SHARE

*What Happens When Observation Becomes Mutual*

CHAPTER FOUR

# The Day the Archive Opened

There was a time when a single satellite image of the Earth cost more than most scientists in the developing world earned in a month. A single Landsat Thematic Mapper scene — one image, covering 185 by 185 kilometres, captured in seven spectral bands — could cost anywhere from six hundred to four thousand four hundred dollars, depending on the era and the supplier. If you wanted to study deforestation in the Amazon, you needed dozens of scenes to cover the area, and dozens more to capture the time series. If you were a researcher in India or Nigeria or Colombia, your annual research budget might not cover the data for a single paper.

I did not experience this. By the time I began working with Landsat, the archive was already free.

I mention this because it matters: I belong to a generation of Earth scientists who have never known a world in which the most important satellite data was locked behind a paywall. For us, opening a browser, navigating to the USGS EarthExplorer portal, selecting a scene, and downloading it is as natural as opening a textbook. We do not think about it. We do not feel grateful in the way that someone who remembers the before would feel grateful. The data is simply there, the way oxygen is there. And like oxygen, we notice it only when we stop to consider what the world would be like without it.

This chapter is about the day the oxygen was released.

* * *

The Landsat programme has been acquiring images of the Earth's surface since 1972. By 2008, when the policy changed, the archive contained over two million scenes. This was, by any measure, the most valuable collection of Earth observation data in existence — thirty-six years of continuous, calibrated, multispectral imagery covering every landmass on the planet. It was a record of how the Earth's surface had changed across nearly four decades: forests cleared, cities built, glaciers retreated, rivers diverted, deserts expanded, coastlines eroded. And for most of its existence, this record was locked behind a price.

The history of Landsat's pricing is a history of policy confusion. When the programme launched in 1972, scenes from the original Multispectral Scanner cost twenty dollars each. By the early 1980s, the Reagan administration, guided by the belief that government data should be commercialised rather than subsidised, transferred Landsat operations to a private company called EOSAT. Prices climbed. A single Thematic Mapper scene rose to four thousand four hundred dollars. Copyright restrictions were imposed on top of the price, meaning that even if you could afford the data, you could not freely share your results. The number of scientists using Landsat plummeted. Research publications that relied on Landsat data declined. The archive grew, but fewer and fewer people could afford to look at what it contained.

Think about what this means. The United States government had spent billions of dollars building and launching satellites, operating ground stations, processing data, and maintaining an archive of planetary observations that stretched back to the Nixon administration. And then it had placed that archive behind a wall that excluded precisely the people who could have used it most — researchers in developing countries, small universities, environmental monitoring organisations, the entire global community of scientists who study the Earth's surface for a living.

The argument for commercialisation was that the private sector would be more efficient, that market pricing would ensure the data went to those who valued it most. The argument against, which eventually prevailed, was simpler: publicly funded data should be publicly available. The Earth belongs to everyone. The images of the Earth, captured by instruments paid for by American taxpayers, should not be the private property of a company that happened to hold the distribution contract.

* * *

In January 2008, the United States Geological Survey announced that the entire Landsat archive would be made available for free download over the internet. No application required. No institutional affiliation checked. No per-scene fee. Just a website, a search function, and a download button. Anyone, anywhere, with an internet connection could now access thirty-six years of the Earth's history as seen from orbit.

The effect was immediate and staggering. In 2001, the USGS had distributed approximately twenty-five thousand Landsat scenes, each sold at six hundred dollars. In 2009, the first full year of free access, nearly one million scenes were downloaded.

By 2017, annual downloads had increased twentyfold compared to 2009. The number of peer-reviewed publications using Landsat data, which had declined during the commercialisation era, surged — reaching nearly sixteen hundred papers in 2017 alone, a more than fourfold increase from the pre-2008 average.

These are not just statistics. Each of those downloads represents a scientist somewhere on the planet asking a question about the Earth and being able to answer it. Each of those publications represents a piece of knowledge that would not exist if a bureaucrat in Washington had not reversed a policy that a different bureaucrat in Washington had implemented twenty-five years earlier. The history of science is often told as a story of discoveries — moments of brilliance, flashes of insight, the lone genius in the laboratory. But it is also, and perhaps more fundamentally, a story of access. Who gets to look? Who gets to know? Who is allowed to see the data, and who is locked out?

The 2008 Landsat decision was not a scientific discovery. It was an act of policy. But it enabled more scientific discovery than most actual discoveries do, because it removed the barrier between the question and the evidence.

* * *

I work in India. India has its own Earth observation programme — one of the most ambitious in the world, in fact. The Indian Space Research Organisation has been launching remote sensing satellites since IRS-1A in 1988. The Resourcesat, Cartosat, and Oceansat series provide data at a range of resolutions and spectral configurations. India's National Remote Sensing Centre in Hyderabad operates a data distribution system that serves Indian researchers and, increasingly, international users. India does not, in any simple sense, depend on Landsat.

And yet, for years, the majority of remote sensing research published by Indian scientists used

Landsat data. This was not because Indian satellites were inferior — in several respects, they were superior, particularly in spatial resolution. It was because Landsat was free, globally consistent, and easy to access. The archive was online. The data format was standardised. The processing chain was documented. A researcher in Chennai could download the same scene that a researcher in Colorado was using, process it with the same algorithms, and produce results that were directly comparable. Landsat had become the common language of Earth observation, and it had become so precisely because it was free.

This is beginning to change. India's Bhoonidhi platform, launched by NRSC, now provides access to Indian satellite data through a modern web portal, and more Indian researchers are using Indian data — as they should, given the investment their country has made in building these instruments. But the pattern that Landsat established remains instructive. When you make data free, you do not just increase the number of users. You change *who* the users are. Before 2008, Landsat was used primarily by well-funded institutions in North America and Europe. After 2008, usage exploded across Asia, Africa, and South America. Scientists who had been priced out of the archive walked in. Questions that had been unaskable — not because the data did not exist, but because the people who needed to ask them could not afford to look — suddenly became researchable.

I think about this when people ask me why open data matters. It does not matter because of an abstract principle about information wanting to be free. It matters because a scientist in Nairobi studying deforestation in the Mau Forest needs the same data that a scientist in Maryland has, and if one of them has to pay six hundred dollars per scene and the other does not, the distribution of knowledge about the Earth's surface will follow the distribution of money rather than the distribution of need. And the Earth does not arrange its problems according to the wealth of the countries that contain them.

* * *

The free Landsat archive was the first act in what I want to call the democratisation of seeing. It was followed by others. The European Space Agency's Sentinel programme, launched in 2014 as part of the Copernicus Earth observation initiative, adopted a free and open data policy from the beginning — having learned, perhaps, from Landsat's decades of costly ambivalence. Sentinel-2, with its ten-metre resolution and five-day revisit time, is now used by more researchers worldwide than any other optical satellite. The entire Copernicus archive is free. The Japanese space agency, JAXA, has made ALOS data freely available. Even commercial satellite companies, while charging for their highest-resolution products, offer free access to lower-resolution archives and educational licences.

Something has shifted in the economics of Earth observation, and it is worth pausing to understand what. For most of the history of satellite remote sensing — roughly 1960 to 2008 — the data was treated as a commodity. It was produced by governments or government-licensed companies, and it was sold to users at a price that reflected (or, in the commercialisation era, exceeded) the cost of production. The logic was the logic of territorial thinking applied to information: this data belongs to the entity that produced it, and access must be controlled, metered, and monetised.

The shift to open data represents a different logic. It says: the Earth's surface is a common concern. The data collected about it, when funded publicly, should be a common resource. The value of satellite data is not in the image itself but in the knowledge that is produced when scientists, policymakers, and citizens can use it freely. Restricting access does not protect the value; it destroys it, because the knowledge that would have been produced never comes into existence.

This is the "Share" in my framework. Seeing the Earth from above is the first step. But seeing is not enough if the seeing is restricted to those who can pay for it, or those whose governments happen to operate satellites, or those who hold the right institutional credentials. The promise of geospatial science is not just that it provides a new view of the planet but that it can provide a *shared* view — a view that is available to all parties in a dispute, all researchers studying a problem, all citizens affected by a decision. The satellite sees the whole Earth. The question is whether the whole Earth gets to see what the satellite sees.

* * *

I began my career after the archive opened. I have never paid for a Landsat scene. I have never been told that the data I need exists but that I cannot afford to look at it. I have never had to choose between studying one region and another because my budget could cover the scenes for one but not both. This freedom shaped my science in ways I am only beginning to understand, because it shaped the questions I thought to ask. When data is free, you think differently. You think bigger. You think about the whole basin instead of one tributary, the whole coastline instead of one bay, the whole decade instead of one year. You think, in other words, at the scale of the Earth itself — which is the scale at which the planet's problems actually operate.

The day the archive opened was not a scientific breakthrough. No new instrument was launched. No new spectral band was discovered. No algorithm was invented. What happened was simpler and, in its consequences, larger: a door that had been closed was opened, and the people who walked through it changed what we know about the planet. They are still walking through it. Every day, somewhere in the world, a researcher downloads a Landsat scene for free and begins to study a piece of the Earth that she could not have studied before 2008. The archive grows. The knowledge grows. And the territorial logic that says information must be owned, controlled, and sold — the same logic that draws lines through river basins and calls them borders — retreats a little further.

Not far enough. Not yet. But the direction is clear, and the evidence is in the numbers: twenty-five thousand scenes distributed in 2001, behind a paywall. One million in 2009, for free. Twenty million by 2017. The curve bends upward, and every point on that curve represents a question about the Earth that someone was finally allowed to ask.

CHAPTER FIVE

# The Photograph as Witness

In 2004, a commercial satellite passed over a village called Donkey Dereis in South Darfur, Sudan. The image it captured showed an intact landscape: hundreds of thatched-roof huts arranged in the loose clusters typical of the region, surrounded by fields, connected by footpaths. A community. By 2006, when another satellite passed over the same coordinates, the village was gone. One thousand one hundred and seventy-one homes had been destroyed. The land was overgrown with vegetation, reclaiming the space where people had lived. The only record that Donkey Dereis had ever existed as a functioning settlement was a satellite image taken two years before its annihilation.

No journalist was present when Donkey Dereis was destroyed. No camera crew filmed the burning. No court had issued an order to document what happened. The Sudanese government, which was responsible for the violence — directly, through its military forces, and indirectly, through the Janjaweed militias it armed and supported — had every reason to deny that the destruction had occurred. And it did deny it, for years, in diplomatic forums, in press conferences, in carefully worded statements to the United Nations.

The satellite did not care about the denial. The satellite had recorded what was there in 2004 and what was not there in 2006, and the difference between the two images was a piece of evidence that could not be argued away, could not be retracted, could not be reinterpreted through the lens of political convenience. Commercially available satellite imagery can resolve objects as small as two feet across — sufficient to show individual structures, to count them, to determine whether they are standing or collapsed or burned. The

American Association for the Advancement of Science, working with Amnesty International and Human Rights Watch, analysed satellite imagery of twenty-eight locations across Darfur and eastern Chad beginning in 2006. Seventy-five per cent of the sites showed destruction of villages, growth of camps for internally displaced persons, or both. The images were provided to the International Criminal Court.

This is what I mean by the photograph as witness. Not a photograph in the ordinary sense — not a picture taken by a person who chose to point a camera in a particular direction, at a particular moment, for a particular reason. A satellite image is something different. It is a record made by a machine that passes over the same ground on a fixed schedule, recording everything below it without selection, without intent, without mercy. It does not choose to photograph the atrocity. It photographs everything, and the atrocity is in the frame because it happened on the ground.

* * *

The twentieth century taught us, among its many difficult lessons, that atrocities thrive in the absence of witnesses. The Holocaust was possible in part because it was hidden — conducted in camps whose locations were secret, whose operations were classified, whose victims were stripped of the means to communicate with the outside world. The Rwandan genocide unfolded with shocking speed in part because the international community did not see it happening in real time, or chose not to look. Srebrenica, Halabja, East Timor — in each case, the gap between the event and the world's awareness of the event was wide enough for governments to deny, minimise, or reframe what had occurred.

Denial is not merely a response to evidence. It is a strategy that depends on the absence of evidence. When a government destroys a village and there is no photograph, the destruction exists only in the testimony of survivors — testimony that can be dismissed as biased, exaggerated, or fabricated.

When a government clears a forest and there is no satellite record of what was there before, the loss is invisible. When a military operation flattens a neighbourhood and the rubble is cleared before anyone arrives to document it, the destruction becomes a matter of competing narratives rather than established fact.

The satellite changes this calculus. It does not eliminate denial — governments will deny what they choose to deny regardless of the evidence. But it makes denial more expensive. It forces the denier to argue not against a person's word, which is easy, but against a measurement, which is harder. The satellite image of Donkey Dereis does not say *who* destroyed the village, or *why*, or *on whose orders*. These questions still require investigation, testimony, and adjudication. But the image does say, with the authority of physics, that the village existed and then it did not. It establishes the *that* — the brute fact of destruction — and the *that* is the thing that denial most urgently needs to erase.

* * *

The use of satellite imagery as legal evidence is younger than most people assume. The first time satellite data appeared before the International Court of Justice was in 1986, in a border dispute between Mali and Burkina Faso. The Court was cautious: it held that satellite-derived maps could not constitute a binding territorial document or a title by themselves, whatever their accuracy and technical value, unless both parties had expressed their acceptance. The satellite image, in other words, was treated as a map — an interpretation of reality, not reality itself.

This caution has softened over time, though it has not disappeared. In the maritime delimitation case between Qatar and Bahrain, decided in 2001, both parties submitted satellite data to support their claims about disputed islands — specifically, to establish whether certain formations were islands with territory and territorial waters, or merely sandbars that vanished at high tide. The satellite data could show water levels and land formation with a precision that no historical map could match. In the case between Nicaragua and Honduras, Honduras used satellite imagery to demonstrate that islands at the mouth of the Rio Coco were formed by sediment deposition, a finding that influenced the Court's decision on how to draw the maritime boundary.

But it is in the field of international criminal law that satellite imagery has found its most consequential role. In 2016, the International Criminal Court convicted Ahmad al-Faqi al-Mahdi of the war crime of destroying cultural heritage in Timbuktu, Mali. Among the evidence presented were satellite images — taken from Google Earth and other open-source platforms — showing the mausoleums and mosques of Timbuktu before and after they were demolished by Islamist militants in 2012. Al-Mahdi was sentenced to nine years in prison. The satellite did not testify in court, but its images did.

In the Darfur cases before the ICC, satellite imagery collected from commercial providers and open-source platforms was used to track the burning and destruction of villages, the movement of troops and displaced populations, and the growth of camps that had not existed before the violence began. The United Nations Institute for Training and Research, through its UNOSAT programme, provided satellite analysis for cases in the Central African Republic as well. In each instance, the satellite served as a witness that could not be intimidated, could not be silenced, and could not be cross-examined into changing its story.

* * *

The satellite's role as witness extends well beyond armed conflict. Consider deforestation. In the Amazon, satellite monitoring systems operated by Brazil's National Institute for Space Research have tracked forest loss since the 1980s, providing the data on which enforcement actions, policy decisions, and international negotiations have been based. When the Brazilian government claims that deforestation is declining, the satellite either confirms or contradicts the claim, and the contradiction is available to anyone with internet access. When logging companies clear forest illegally, the satellite detects the clearing — often within days, using near-real-time alert systems — and the detection becomes a potential piece of evidence in criminal proceedings.

In Ecuador, the A'i Cofán indigenous community and their legal team used satellite data to support a case against illegal gold mining on their ancestral lands. Drone footage was combined with satellite imagery and maps to demonstrate the scale of destruction — polluted rivers, compacted soil, deforested hillsides — at a level of detail that eyewitness testimony alone could not have provided. In Suriname, satellite data from Global Forest Watch revealed approximately forty-four thousand seven hundred hectares of tree cover loss from logging and mining activities within and around

Saamaka Maroon territory between 2001 and 2022. The data became part of the legal record in a case about indigenous land rights.

These cases share a common structure. In each one, a powerful actor — a government, a military, a corporation — has an interest in denying or minimising the damage it has caused. And in each one, the satellite provides a record that is independent of the powerful actor's account of events. The satellite does not work for the government. It does not work for the corporation. It does not work for the victims, either. It works for no one. It records the surface of the Earth, and the surface of the Earth bears the marks of what has been done to it.

* * *

I do not want to overstate what satellite imagery can do as evidence. There are real limitations, and they are worth naming. A satellite image shows what happened to the surface. It does not show who did it. It does not show intent. It does not capture the chain of command, the orders given and received, the decisions that led to the destruction. These things must still be established through traditional methods of investigation — testimony, documents, intercepted communications, forensic analysis. The satellite provides the *what* and the *where* and, because of its repeated pass schedule, the *when*. It does not provide the *who* or the *why*.

There is also the question of manipulation. Satellite data consists of numbers — digital values recorded by sensors and transmitted to ground stations. In principle, these numbers can be altered, and in some cases the alteration would be difficult to detect. Courts have been cautious about this, rightly so. The chain of custody for satellite data — from sensor to ground station to archive to analyst to courtroom — must be documented with the same rigour that applies to any other form of forensic evidence.

And there is the problem of access. High-resolution commercial imagery — the kind that can resolve individual structures — is expensive. It is produced by companies like Maxar, Planet, and Airbus, and while some of it is made available for humanitarian purposes, much of it remains behind a paywall. The irony is sharp: the same chapter of this book that described the liberation of the Landsat archive must also acknowledge that the highest-resolution imagery — the imagery most useful for documenting specific acts of destruction — is still, in many cases, a commodity. The eye in the sky sees everything, but showing what it sees to the people who need it most still costs money.

Despite these limitations, the trajectory is clear. Satellite imagery is becoming an accepted and increasingly expected form of evidence in international legal proceedings. The AAAS, UNOSAT, Human Rights Watch, Amnesty International, and a growing number of investigative organisations now routinely use satellite analysis in their documentation of atrocities, environmental crimes, and territorial violations. The International Criminal Court has received satellite evidence in multiple cases. National courts in several countries have admitted satellite imagery in disputes over land use, environmental damage, and property boundaries.

* * *

The photograph as witness. I use the word *witness* deliberately, because a witness is not just someone who sees. A witness is someone whose seeing is made available to others — to a court, to the public, to the historical record. The satellite sees constantly, but it becomes a witness only when its images are retrieved, analysed, and presented in a context where they can change what people believe and what institutions do.

This is the second dimension of sharing. The previous chapter was about sharing the data — making the archive free, so that anyone can see what the satellite sees. This chapter is about sharing the truth — using the data as evidence, presenting it in courts and commissions and news broadcasts, making it impossible to deny what happened on the ground. The satellite does not judge. It does not accuse. It does not have an opinion about who is right and who is wrong. But it provides something that every system of justice requires and that every system of denial seeks to destroy: a record of what was there, made by an observer that cannot be bought, threatened, or silenced.

I find this empowering. I am a scientist, not a lawyer and not a journalist. But I work with the same instruments and the same data that are now being used to hold governments accountable for the destruction of villages, to prosecute the men who demolished the mausoleums of Timbuktu, to prove that a forest was standing before a corporation claimed it was always a wasteland. The same bands I use to calculate vegetation indices are the bands that show whether a village was intact or destroyed. The same sensor that records crop health records the footprint of a bomb. The science I practice is, whether I intended it or not, part of a system of witnessing. And I have come to believe that this is not a distraction from the science but one of its highest purposes: to see what is there, and to make the seeing available to those who need it.

CHAPTER SIX

# The Map That Nobody Owns

One billion people are missing from the world's maps. The figure is an estimate from the Humanitarian OpenStreetMap Team, of the number of human beings who live in places that have never been mapped in any publicly accessible database — places where no road has been traced, no building footprint drawn, no clinic or school or water point marked. These are not uninhabited places. They are places where people are born, grow ill, fetch water, send children to school, and die, all without appearing on any map that a government agency, an aid organisation, or a search-and-rescue team could use to find them.

Think about what it means to be unmapped. If a flood strikes your village and you are not on a map, the relief workers do not know your village exists. If a disease outbreak begins in your district and the nearest clinic is not marked on any map, the epidemiologist planning the vaccination campaign cannot route supplies to it. If your neighbourhood burns and you call for help, the fire truck cannot find you — not because the driver is incompetent but because the street you live on does not exist in any navigation system. To be unmapped is to be invisible to the institutions that organise modern life, and the people who are most likely to be invisible are, with depressing consistency, the people who most need to be seen.

This chapter is about the people who decided to fix this — not governments, not space agencies, not corporations, but volunteers. Hundreds of thousands of them, sitting at their computers in cities and towns across the world, tracing roads and buildings from satellite imagery, contributing to a map that nobody owns and everyone can use. The map is called OpenStreetMap, and it is, I believe, one of the most remarkable acts of collective knowledge-building in human history.

* * *

OpenStreetMap was founded in 2004 by Steve Coast, a British computer scientist who was frustrated that the Ordnance Survey — the United Kingdom's national mapping agency — held Crown copyright over its map data, making it expensive and legally complicated for anyone to use the maps that their own taxes had funded. The logic was familiar: publicly funded data, locked behind restrictions. Coast's response was to start building a map from scratch, using GPS traces collected by volunteers who walked, cycled, and drove through their neighbourhoods, recording the paths they took and the features they passed.

The idea was modelled on Wikipedia: an open, editable, freely licensed database of geographic information, maintained by a global community of contributors. Anyone could sign up.

Anyone could edit. The data was released under an open licence that allowed anyone to use it, for any purpose, provided they credited the source and shared any improvements. There was no charge, no institutional gatekeeping, no requirement that you hold a degree in cartography or geography. If you knew where a road was, you could add it. If you noticed that a map was wrong, you could fix it.

Twenty years later, OpenStreetMap is the largest open geographic database in the world. More than three hundred thousand active contributors edit it each year, making roughly three hundred million changes annually. Its data underpins navigation applications, humanitarian response platforms, academic research, and government services in countries where official mapping agencies lack the resources or the will to map every settlement. It has been translated, in effect, from a British protest against copyright into a global infrastructure for geographic knowledge.

I use it in my own work. Not always — satellite imagery remains my primary data source. But when I need a road network, an administrative boundary, a building footprint in an area where no commercial provider has bothered to map, OpenStreetMap is where I go. And what I find there, more often than not, was put there by someone I will never meet, in a country I may never visit, who decided that this particular stretch of road or this particular school deserved to exist on the map.

* * *

On 12 January 2010, a magnitude 7.0 earthquake struck Haiti, devastating the capital, Port-au-Prince, and killing an estimated two hundred and twenty thousand people. The international humanitarian response was massive and immediate. But there was a problem: Haiti was barely mapped. The available maps of Port-au-Prince were outdated, incomplete, and in many areas simply blank. Relief organisations could not coordinate effectively because they did not have a reliable map of the city they were trying to save.

Within hours of the earthquake, the OpenStreetMap community mobilised. Satellite companies released post-disaster imagery. And volunteers — over six hundred of them, from an estimated twenty-nine countries, most of whom had never been to Haiti — began to map. They sat at their computers in Europe, North America, Asia, and Africa, opening satellite images of a destroyed city, and tracing every road, every building, every feature they could identify. Within thirty days, the entire national road network of Haiti and one hundred per cent of the Port-au-Prince road network had been mapped. Approximately ninety-nine per cent of the data had been created after the earthquake — meaning that virtually the entire map of Haiti's capital was built from nothing in a month.

The map became the operational base for the response. The American Red Cross used it. The United Nations used it. The World Bank used it. The

United States Marine Corps used it. Urban search-and-rescue teams used it to navigate a city whose landmarks had collapsed, whose street signs had been buried in rubble, whose familiar geography had been rearranged by the force of the quake. The map that nobody owned became the map that everybody needed.

I dwell on Haiti because it established a pattern that has been repeated, with variations, in every major disaster since. When a 7.8 magnitude earthquake struck Nepal in April 2015, over eight thousand OpenStreetMap volunteers from around the world mapped the affected area within weeks. The data was used by the American Red Cross, the World Bank, and the Nepalese government to coordinate search-and-rescue operations, identify displaced populations, and plan reconstruction. When the Kerala floods struck southern India in 2018, local and international volunteers mapped roads, shelters, and flood-affected areas in real time. When the earthquake hit Turkey and Syria in February 2023, the mapping response was faster still

— because the tools were better, the community was larger, and the precedent was established.

* * *

In November 2014, the American Red Cross, the British Red Cross, Médecins Sans Frontières, and the Humanitarian OpenStreetMap Team launched a project called Missing Maps. The premise was simple and troubling: the places most vulnerable to disasters, disease, and conflict were also the places least likely to be mapped. Disaster response was reactive — the community mobilised after the earthquake, after the flood, after the outbreak. Missing Maps proposed something different: map the vulnerable places *before* the disaster, so that when it comes, the responders already have the data they need.

The project works in three stages. First, remote volunteers trace buildings and roads from satellite imagery, adding the basic geometry to OpenStreetMap. Second, local community members add detail — the names of streets, the locations of health facilities, the boundaries of neighbourhoods — because this is knowledge that no satellite can capture and no remote volunteer can guess. Third, the resulting data is used by humanitarian organisations to plan disaster preparedness, vaccination campaigns, and development programmes.

Over the past decade, the Humanitarian OpenStreetMap Team has enabled the contributions of more than two hundred thousand volunteers, who have collaboratively mapped areas home to more than one hundred and fifty million people. The data has supported humanitarian response to nearly one hundred disasters and crises. And the goal — announced in partnership with the Audacious Project — is to map, within the next five years, the places home to one billion people across ninety-four countries.

These numbers deserve a moment of reflection. Two hundred thousand volunteers. One hundred and fifty million people mapped. One billion still to go. This is not the work of a government. It is not the work of a corporation. It is not the work of any single institution. It is the work of a network — a loosely organised, globally distributed community of people who believe that everyone deserves to exist on a map, and who are willing to spend their evenings and weekends making it so.

* * *

The fact that OpenStreetMap is owned by nobody is not incidental. It is the point. Consider what it means, in the context of everything this book has argued so far, to have a map that does not belong to any government.

Throughout history, maps have been instruments of power. The Survey of India, as I discussed in the first chapter, was an act of colonial administration. National mapping agencies exist, in part, to assert sovereignty — to define the boundaries of the state and to control the representation of its territory. This is why India, Pakistan, and China each produce different maps of Kashmir: because the map is not a neutral description of the land but a claim about who owns it. To map a territory is to assert authority over it. To control the map is to control the narrative.

OpenStreetMap disrupts this logic. It does not belong to India or Pakistan or China. It does not assert any territorial claim. When a volunteer in Bangalore maps a road in Port-au-Prince, no sovereignty is being exercised. When a volunteer in Nairobi maps a clinic in Kathmandu, no colonial apparatus is at work. The map is produced by people for people, under a licence that guarantees it will remain free, and the result is a geographic database that is, by its nature, post-territorial. It does not care about borders. It does not draw them in colours that favour one claim over another. It simply records what is on the ground, as reported by the people who live there or who can see it from the satellite imagery.

This is not to say that OpenStreetMap is without politics. It has its own governance disputes, its own biases (urban areas are better mapped than rural ones; the Global North is better covered than the Global South), and its own arguments about data quality, vandalism, and the limits of volunteer labour. But the fundamental architecture of the project — open data, open contribution, no single owner — represents something genuinely new in the history of cartography. For the first time, the map of the world is being built not by empires or agencies but by the collective effort of ordinary people, and the result belongs to everyone.

* * *

There is a criticism of volunteer mapping that I take seriously: that untrained mappers introduce errors, that the quality of crowd-sourced data cannot match the quality of professionally surveyed data, that allowing anyone to edit a map is a recipe for inconsistency. These concerns are legitimate. A remote volunteer tracing buildings from satellite imagery can misidentify a shadow as a structure, or miss a footpath that is invisible from above, or draw a road where a river actually runs.

But there is something that the remote volunteer, working alone from a satellite image, cannot do and that only a local person can: name the place. Know that the building on the corner is a clinic, not a warehouse. Know that the road floods every monsoon. Know that the settlement on the hill is called something different by the people who live there than by the government that administers it. Local knowledge is irreplaceable, and OpenStreetMap, at its best, is a platform that combines the view from above — the satellite image, the remote trace — with the view from within — the local contributor who knows the ground.

This combination is, I think, a model for how geospatial science should work more broadly. The satellite sees the Earth from orbit. It sees patterns, extents, changes over time. But it does not know the names of things, or the uses of buildings, or the social meaning of the spaces it observes. That knowledge lives in people, and it can only be captured by asking them — or, better, by giving them the tools to add it themselves. OpenStreetMap is the largest experiment in this combination that the world has yet conducted, and the results suggest that it works. Not perfectly. Not without error. But well enough to save lives in Haiti, in Nepal, in Kerala, and in the ninety-four countries where the next billion people are waiting to be mapped.

There is, however, a deeper difficulty here than errors of tracing. This book has argued that geospatial science offers a way of seeing the Earth that is closer to physical reality than the political map — that the satellite's measurements are more reliable than governments' claims. But measurements are not neutral. They are taken by instruments designed by particular people, calibrated for particular purposes, and interpreted through particular frameworks. There are communities — indigenous peoples, pastoral nomads, traditional farming societies — whose spatial knowledge is fundamentally relational: it is embedded in seasonal movement, oral transmission, and relationships between people and land that no satellite band can capture. For a Toda pastoralist in the Nilgiris, the boundaries of grazing territory are not fixed lines but shifting agreements negotiated across generations. For an Adivasi community in Jharkhand, the forest is not a land-cover category but a social fact whose meaning cannot be expressed in a GIS layer. To position the satellite as the arbiter of spatial truth in such contexts is not scientific objectivity; it is a different kind of erasure, replacing the political map with a technological one. Geospatial science at its best acknowledges this: the view from above is one perspective, not the only one, and the people whose lives are marked on the map must be parties to how it is drawn.

A related difficulty concerns access. This chapter has celebrated the billion people waiting to be mapped. But there is a prior question: who has access to the tools of mapping? Free Landsat data requires an internet connection, a computer, and the processing skills to use it. A smartphone running Google Earth requires connectivity infrastructure that does not exist in the same areas where the one billion unmapped people live. The volunteer mappers who responded to the Haiti earthquake were, overwhelmingly, residents of the Global North with broadband connections and free evenings. The democratisation of seeing is real, and it is meaningful. But it is incomplete in a way that maps onto existing patterns of inequality with uncomfortable precision: the people most in need of being seen are still, in many cases, least equipped to see for themselves. The goal of the Missing Maps project — to map the most vulnerable places before the disaster strikes — is admirable and urgent. But the map that nobody owns is still, in its production, shaped by those who have the tools to build it. Closing that gap is a material problem, not a software problem, and it demands more than an open licence.

* * *

The map that nobody owns. I return to that phrase because it is the purest expression of what the “Share” in my framework means. The previous chapters described the sharing of data (the Landsat archive opened) and the sharing of evidence (the satellite as witness). This chapter describes something larger: the sharing of the map itself. Not just the data but the act of mapping — the power to say what exists, where it is, and what it is called. That power, which for most of human history has belonged to states and empires, is now distributed across a global network of volunteers who do not seek profit, do not exercise sovereignty, and do not ask permission.

When I think about the child who coloured in political maps in school — the child who was given a map and told to fill in the names of places that someone else had decided mattered — I think about how different the experience would be if that child were given a blank screen, a satellite image, and told: *you decide what goes on the map*. Not a government. Not an empire. Not a textbook. You. This is what OpenStreetMap offers, and it is, in the context of a world that has spent four centuries insisting that maps belong to the powerful, a quiet revolution.

One billion people are still missing. The map is still incomplete. But it is being built, every day, by people who believe that the Earth belongs to everyone who lives on it, and that the map of the Earth should too. Every building traced, every road drawn, every clinic named is an act of inclusion — a declaration that this place exists, that these people matter, that the blank spot on the map was never empty. It was only unseen.

PART THREE

# SHIFT

*When Seeing Changes Acting*

CHAPTER SEVEN

# The Classroom Globe Is Wrong

There is a map hanging on the wall of nearly every classroom in the world, and it is wrong. Not wrong in the way that an outdated textbook is wrong — overtaken by new discoveries but once accurate. Wrong in a more fundamental sense: wrong by design. The Mercator projection, created by the Flemish cartographer Gerardus Mercator in 1569 for the purpose of maritime navigation, distorts the size of landmasses in direct proportion to their distance from the equator. Countries near the poles are stretched. Countries near the equator are compressed. The result is a map on which Greenland appears to be the same size as Africa, when in reality Africa is fourteen times larger. A map on which Europe looms over the southern hemisphere like a continent of equal or greater size, when the truth is that you could fit the United States, China, India, Japan, Mexico, and most of Europe inside Africa and still have land to spare.

I show this to people — colleagues, students, friends — and they are shocked. Every time. It does not matter how educated they are, how well-travelled, how familiar with geography. The Mercator distortion is so deeply embedded in the way we imagine the world that even people who know about it intellectually are startled when they see it corrected. There is a website called The True Size Of, which allows you to drag the outline of one country onto another and watch it resize according to the actual area. Drag India from its position near the equator up to the latitude of Scandinavia, and it swells to cover most of Northern Europe. Drag Africa up to North America, and it dwarfs the United States. The exercise is playful, but the feeling it produces is not. It is the feeling of having been lied to — not deliberately, not maliciously, but systematically, by every map you have ever seen on a classroom wall.

The Mercator projection was not designed to deceive. It was designed to preserve the angles between compass bearings, which is useful if you are a sixteenth-century navigator plotting a course across the Atlantic. But it was never intended to be used as a general-purpose map of the world, and the fact that it became one — that it was adopted by classrooms, atlases, news broadcasts, and wall posters as the default representation of the Earth — is a failure of education, not of cartography. The cartographer told us what the map was for. We ignored him and hung it in every school.

* * *

The classroom globe is better than the Mercator map, in the sense that a sphere does not distort the relative sizes of continents. But the globe teaches its own lessons, and not all of them are accurate. The classroom globe is a political globe. It is painted in the coloured shapes I described in the first chapter of this book — each country a distinct hue, each border a clean line, the world divided into sovereign parcels as neatly as a stained-glass window. The child who spins the globe learns, without anyone saying so explicitly, that the world is *made* of countries. That the natural unit of geography is the nation-state. That the most important thing about any point on the Earth's surface is which coloured shape it belongs to.

This is what I mean by the classroom globe being wrong. Not wrong in its geometry — a sphere is the correct shape for depicting a sphere — but wrong in its pedagogy. It teaches territorial thinking as the default way of understanding the Earth. It presents political boundaries as the primary geographic fact, when in reality they are among the most recent and most arbitrary features of the planet's surface. The Himalayas are fifty million years old. The Indian Ocean is one hundred and fifty million years old. The border between India and Pakistan is seventy-eight years old. But on the classroom globe, the border is drawn with the same confidence as the coastline, and the child who spins the globe does not learn to distinguish between the two.

I was that child. I spun the globe. I learned the coloured shapes. And it took me the better part of two decades — an undergraduate degree, a master's degree, a doctoral programme, and the beginning of a research career — to unlearn what the globe had taught me. To see the Earth not as a collection of sovereign territories but as a continuous physical system that happens to have been divided, very recently in geological terms, by a species that has a habit of drawing lines.

* * *

In Indian schools, geography is taught as a subject within social science. Students learn about rivers, mountains, climates, and agricultural zones, and they learn about states, capitals, boundaries, and political divisions. The two categories — physical geography and political geography — are presented as distinct topics within the same subject, but the political geography always wins. Ask an Indian student to draw India, and she will draw the political outline — the shape she has practised in dozens of map exercises, filling in state boundaries and marking capitals with stars. She will not draw the watershed of the Ganges, or the track of the monsoon, or the gradient of the Western Ghats. She has learned these things, but they are not what the map exercise asks for. The map exercise asks for the coloured shapes.

GIS was introduced into India's higher secondary curriculum in 2000, under the National Curriculum Framework for School Education. Under the revised framework of 2005, it received expanded coverage. On paper, this means that students in classes eleven and twelve can encounter remote sensing, satellite imagery, and geographic information systems as part of their geography education. In practice, the implementation has been uneven. The reason is familiar to anyone who has worked in education: the technology exists, but the teachers have not been trained to use it. GIS remains, in the words of one assessment, at an "incipient stage" in Indian schools, present in the textbook but largely absent from the classroom.

At the university level, the situation is different. India has a strong and growing ecosystem of geospatial education. The Indian Institute of Remote Sensing in Dehradun, established by ISRO, offers postgraduate programmes that train hundreds of students each year. Anna University in Chennai runs an Institute of Remote Sensing. Departments of geography and Earth science at universities across the country teach GIS, remote sensing, and spatial analysis as core components of their curricula. The students who pass through these programmes emerge with a way of seeing the Earth that is fundamentally different from what they learned in school. They learn to think in terms of data, not shapes. Wavelengths, not colours. Measurements, not claims.

But this transformation happens only at the university level, and only for students who choose geography or Earth science as a specialisation. The vast majority of Indian students — the ones who become engineers, doctors, lawyers, civil servants, businesspeople, politicians — leave school with the same geographic education I received: political maps, coloured shapes, the world as a collection of sovereign territories. They carry this mental model into adulthood, into professions, into positions of power, and they make decisions about water, land, climate, and borders on the basis of a geography they learned at fourteen and never revised.

* * *

Imagine a different curriculum. Imagine that every Indian student, by the age of sixteen, had been taught not only where the states are on the map but what the land actually looks like from above. Imagine that the geography class included, alongside the political map of India, a Landsat false-colour composite of the same region — vegetation in red, water in black, bare soil in grey. Imagine that the student was asked not just to label the Cauvery River but to trace its watershed, to see that the river begins in one state and ends in another, and to understand that the water does not stop at the state boundary.

Imagine that the student was shown a time-series of satellite images — the same place, photographed every year for twenty years — and asked to describe what has changed. The forest that was there in 2005 and gone by 2015. The city that was a town in 2000 and a metropolis by 2020. The glacier that has been retreating, centimetre by centimetre, for three decades. Imagine that the student was given, not a globe painted in sovereign colours, but a digital globe — one she could rotate, zoom into, overlay with data layers, switch between political boundaries and elevation models and vegetation indices and nighttime lights.

This is what I mean by geospatial literacy. Not GIS training — not the ability to operate ArcGIS or write Python scripts for raster analysis, which are skills for specialists. Geospatial literacy is something more basic and more important: the ability to read the Earth the way one reads a text. To understand that every map is a projection, and every projection distorts. To know that the political map is one representation among many, and not necessarily the most truthful. To recognise that the Earth's systems — water, weather, vegetation, soil, migration — operate at scales and across boundaries that the political map cannot represent. To be, in short, a citizen who is not fooled by the coloured shapes.

This is not a utopian proposal. The data is free. The tools are free. Google Earth is free. QGIS, the open-source geographic information system, is free. Landsat imagery is free. Sentinel imagery is free. OpenStreetMap is free. The only thing that is not free is the curriculum time and the teacher training required to bring these tools into the classroom. And the reason that investment has not been made, I suspect, is not that it is expensive — it is less expensive than the science laboratories that every school is expected to maintain — but that it has not been understood as urgent. Geography education is treated as a settled matter. The maps are on the wall. The textbooks are printed. What more is there to teach?

* * *

There is a politics to the Mercator projection that is worth naming, even if Mercator himself did not intend it. The projection inflates the northern hemisphere and shrinks the equatorial regions. This means that Europe, Russia, Canada, and the United States appear larger than they are, while Africa, South America, India, and Southeast Asia appear smaller. For centuries, the Mercator map was the map of empire — the map that hung in the offices of colonial administrators, on the walls of European capitals, in the classrooms where future rulers were educated. And the visual effect of the projection, whether intended or not, reinforced the idea that the northern, colonising nations were larger, more important, and more central to the world than the southern, colonised ones.

This is not a conspiracy theory. It is an observation about the relationship between representation and perception. When you grow up looking at a map on which Africa is compressed and Europe is enlarged, you absorb, below the level of conscious reasoning, a sense of relative importance that corresponds to relative size. The map does not say that Europe matters more than Africa. But the map makes Europe look bigger, and human cognition, which is relentlessly visual, draws its own conclusions.

In 1973, the German historian Arno Peters published a projection that attempted to correct this distortion. The Peters projection preserves the relative areas of landmasses at the expense of their shapes — Africa and South America appear elongated, stretched vertically, in a way that many cartographers found aesthetically objectionable. The ensuing debate, sometimes called the "map wars," was bitter and, in retrospect, instructive. Cartographers argued about which distortion was more acceptable. Politicians argued about which map told the truth. And underlying both arguments was a question that neither side fully articulated: *who gets to decide what the world looks like?*

The satellite answers this question with disarming simplicity. The satellite does not use a projection. It photographs the Earth as it is: a sphere, seen from above, with no need to flatten it onto a page. When you look at the Earth in Google Earth, you are looking at a representation that is closer to the truth than any paper map can be, because it does not distort the size of continents, does not privilege one hemisphere over another, and does not paint the land in sovereign colours unless you ask it to. The satellite image is not a perfect representation of reality — nothing is. But it is the least politically distorted representation we have, and for that reason alone, it belongs in the classroom.

* * *

This chapter is the first in the final part of this book, and the final part is about a word I have been building toward: *Shift*. See the Earth from above. Share the data freely. And then: shift how we think about the Earth, starting with how we teach our children to see it.

Political maps serve a purpose: they tell you which laws apply where, which government provides services, which passport you need. What this chapter argues is that the political map should no longer be the *only* map — or even the *first* map — that a child encounters. Before the coloured shapes, before the borders, before the sovereignty, show the child what the Earth actually looks like. Show her the rivers that cross borders. Show her the forests that do not know which country they are in. Show her the monsoon that does not stop at the Line of Control. And then, when you give her the political map, she will see it for what it is: one way of organising the world, not the way the world is.

I think about the boy I was, filling in those blank maps in school. I coloured India with pride, and I was right to feel that pride. But I was given only one kind of map, and that one kind of map trained me to think in only one way. It took me twenty years and a career in geospatial science to learn that there were other ways of seeing. That is too long. It should not require a doctorate to understand that the classroom globe is wrong. It should require only a different globe — one that shows the Earth as the satellite sees it, uncoloured, undivided, and continuous. The technology for this globe exists. The data is free. The question, as always, is whether we choose to use it.

CHAPTER EIGHT

# Sovereignty from Space

In the early 1960s, a photograph was taken at the Thumba Equatorial Rocket Launching Station in Kerala that has become one of the defining images of India's space programme. It shows the nose cone of a sounding rocket being transported to the launch pad on a bicycle. There is another photograph from the same era: a rocket part being carried on the back of a bullock cart. These images are often shared with a kind of affectionate pride — look where we started, look where we are now. But they contain a more serious point. India built its space programme not from abundance but from constraint. The bicycle was not a quaint choice. It was the available technology. And the willingness to begin with a bicycle, when others began with billion-dollar budgets, is the reason that India today operates one of the most capable Earth observation programmes in the world at a fraction of the cost of any comparable system.

ISRO's annual budget in 2023–24 was approximately 1.55 billion dollars in nominal terms. NASA's was 25.4 billion. The ratio is roughly one to sixteen. And yet India has launched over fifty Earth observation satellites, operates a fleet that includes the Resourcesat, Cartosat, and Oceansat series, has sent a spacecraft to Mars for seventy-four million dollars — less than the production budget of the Hollywood film *Gravity* — and has landed a rover on the Moon's south pole. The Mangalyaan Mars mission cost less than one-eighth of NASA's MAVEN orbiter, which launched in the same year for the same destination.

I mention these numbers not to make a nationalist argument. I am a scientist, and for me ISRO is, first and above all, a scientific tool. The satellites it launches produce the data I work with. The sensors it builds determine what I can measure.

The archive it maintains is the record from which I draw conclusions about the Earth's surface. When I think about ISRO, I think about spectral bands and spatial resolution and revisit times. But I would be dishonest if I pretended that the scientific tool exists in a vacuum, separated from the country that built it and the reasons it was built. ISRO is a scientific tool. It is also an assertion — that India can see its own land with its own eyes, from its own instruments, on its own terms.

* * *

Vikram Sarabhai, the physicist who founded India's space programme in 1962, made an argument that was unusual for its time and remains unusual today. He argued that a developing country — a country with mass poverty, low literacy, and limited infrastructure — not only could afford a space programme but could not afford to be without one. Space technology, Sarabhai believed, was not a luxury for rich nations but a necessity for poor ones.

Satellites could provide communication to remote villages. Weather forecasting could save harvests. Earth observation could map resources, monitor droughts, and plan development. The case was not that India should go to space because space was prestigious. The case was that India should go to space because India's problems were so large that only a view from above could encompass them.

India's first remote sensing satellite, IRS-1A, launched on 17 March 1988 from the Soviet Cosmodrome at Baikonur. It carried two cameras — LISS-I with a resolution of seventy-two metres and LISS-II with a resolution of thirty-six metres. By the standards of the time, this was respectable but not exceptional. What was exceptional was the intent. India was not launching a satellite to photograph other countries. It was launching a satellite to see itself — to map its own forests, monitor its own crops, plan its own cities, and manage its own water resources. The satellite was an instrument of self-knowledge.

Before IRS-1A, if India wanted satellite imagery of its own territory, it had to obtain it from foreign sources — primarily from the United States, through Landsat, or from France, through SPOT. This was not merely inconvenient. It created a dependency that had both practical and symbolic dimensions. Practically, India was subject to the data policies, pricing decisions, and access restrictions of other nations. Symbolically, it meant that India could not see itself except through instruments that belonged to someone else. For a country that had gained its political independence in 1947, this form of observational dependence was a lingering asymmetry — a reminder that sovereignty, in the age of satellites, required not just control over territory but control over the ability to see that territory.

IRS-1A changed this. Not completely — India continued to use Landsat and other foreign data, and continues to do so today. But the principle was established: India would build its own eyes. Over the next three decades, ISRO launched a succession of increasingly capable Earth observation satellites. Resourcesat-1 in 2003, with twenty-three-metre resolution and three spectral bands optimised for agriculture and water resources. Cartosat-1 in 2005, with 2.5-metre resolution for large-scale mapping. Cartosat-3 in 2019, with resolution better than one metre — sufficient to identify individual vehicles and structures. Each satellite represented an expansion of what India could see and, by extension, what India could know about itself.

* * *

The phrase I want to introduce here is *sovereignty over seeing*. It is not a phrase you will find in the political science literature, but I think it captures something that the existing vocabulary does not. We are accustomed to thinking about sovereignty in terms of territory — the right to govern a bounded space. We are less accustomed to thinking about sovereignty in terms of observation — the right to see your own land, from above, using your own instruments, without depending on another nation's willingness to provide the data.

But in the twenty-first century, this second form of sovereignty matters as much as the first. A country that cannot observe its own borders, its own forests, its own coastline, its own cities is a country that depends on others for basic information about itself. If the data comes from a foreign satellite, it comes with conditions — conditions of access, conditions of use, conditions of timing. The foreign satellite may not photograph the area you need, at the time you need it, at the resolution you require. Its archive may be subject to a pricing policy that puts the data beyond your budget. Its government may restrict access for reasons of national security that have nothing to do with your national security.

India's decision to build its own Earth observation programme was, among other things, a decision to liberate itself from this dependency. And it is a decision that an increasing number of countries are now making. More than twenty-one African countries have established space programmes. Eighteen have launched at least one satellite. Nigeria, Egypt, South Africa, Morocco, and Algeria each have active Earth observation capabilities. Brazil launched its Amazonia-1 satellite in 2021, dedicated to monitoring deforestation in the Amazon basin — a task that is too important to Brazil's sovereignty and too sensitive in its implications to be entrusted to another nation's instruments. Indonesia is building its Nusantara Earth Observation constellation. Over sixty-five satellites have been launched by African nations, with more than one hundred and twenty additional satellites in development.

This proliferation of national Earth observation programmes is, in one sense, a continuation of territorial thinking — each country building its own instruments to observe its own territory. But it is also something more complicated, and potentially more hopeful. Because the data that these satellites collect does not stop at borders. An

Indian satellite photographing the Thar Desert photographs Pakistan's Sindh province in the same frame. A Nigerian satellite imaging the Lake Chad basin images Chad, Cameroon, and Niger as well. The satellite sees the region, not the nation, and the data it produces is an invitation — accepted or refused, depending on the politics of the moment — to think in regional terms rather than purely national ones.

* * *

Here is the paradox that this chapter must confront: the instruments that give nations sovereignty over seeing also produce data that undermines the logic of sovereignty itself. Every national satellite is launched to serve national interests. But the images it captures are borderless. The sensor does not adjust its spectral range when it crosses a frontier. The orbit does not pause to respect a territorial claim. The data that flows down to the ground station contains, embedded in its pixels, a view of the world that is fundamentally at odds with the political system that paid for the satellite.

Consider ISRO's Cartosat-3, launched in 2019. It orbits the Earth at an altitude of approximately five hundred and nine kilometres. At that altitude, the satellite's swath width — the strip of ground it photographs in a single pass — is sixteen kilometres across. As it passes over the northern part of the Indian subcontinent, it photographs Punjab. Not Indian Punjab or Pakistani Punjab — Punjab. Both sides. The same sensor, the same resolution, the same spectral bands. The data it collects about the agriculture on the Indian side of the border is identical in format and quality to the data it collects about the agriculture on the Pakistani side. If you were to remove the political overlay, if you were to look at the raw image without knowing where the border was, you would see a single agricultural plain, irrigated by the same river system, growing the same crops, suffering the same water stress.

India's satellites see India. But they also see everything around India, and what they see around India looks, in the data, remarkably like India. The Thar Desert does not change its spectral signature at the border. The Ganges-Brahmaputra delta does not distinguish between Bangladesh and West Bengal. The Western Ghats do not stop at the Kerala-Karnataka boundary — a fact that, as I discussed in an earlier chapter, has consequences for how we think about water.

This is the paradox of sovereignty from space. The satellite is an instrument of national power. But the data it produces is an argument for post-national thinking. It shows you your country, yes. But it also shows you that your country is part of a continuous surface, that its boundaries are political facts imposed on physical continuities, and that the Earth, seen from five hundred kilometres above, does not know or care about the lines we have drawn on it.

* * *

I am not a political scientist, and I do not presume to design new systems of governance. But I can describe what the data shows, and what the data shows is that many of the problems we face — water management, air pollution, deforestation, climate adaptation, disaster response — operate at scales that do not correspond to national boundaries. The monsoon does not respect borders. The aquifer does not stop at the Line of Control. The cyclone does not check which country it is about to strike. And the satellite, which sees all of these phenomena from above, provides the data for managing them at the scale at which they actually occur.

What would it mean to govern the Earth's resources at the scale of the data? Not to abolish nations — that is neither possible nor, in my view, desirable. But to recognise that some problems require governance structures that are larger than nations, and that the data to support those structures already exists. The Indus Waters Treaty of 1960, which divides the rivers of the Indus basin between India and Pakistan, was negotiated with the data that was available in the 1950s — ground-level measurements, hydrological surveys, and the best estimates that mid-century science could provide. Today, both countries have satellites that can measure the snowpack in the Karakoram, the flow rate of the Indus and its tributaries, the soil moisture in the agricultural plains, and the volume of water in the reservoirs — all in near-real time, all with a precision that the treaty's authors could not have imagined.

What if the data were shared? Not the satellites — those will remain national assets, and rightly so. But the data. What if India and Pakistan, instead of relying on a sixty-five-year-old treaty and the political goodwill of a bilateral commission, could both access the same satellite-derived measurements of the basin they share? What if the farmers in Indian Punjab and Pakistani Punjab could see the same soil moisture map, derived from the same sensor, showing them that they are drawing from the same aquifer? The data would not resolve the political dispute. But it might make the physical reality harder to ignore.

This is what I mean by post-territorial governance — not the abolition of territory but the recognition that some forms of governance must operate at scales that territory cannot contain. The river basin. The monsoon system. The tectonic plate. The atmosphere. These are the natural units of the problems we face, and the satellite sees them as such. The shift I am arguing for is not a shift away from nations but a shift in how nations use the data their own satellites produce. The irony is exquisite: the very instruments that nations build to assert their sovereignty produce data that argues for cooperation. The satellite is a nationalist tool that generates internationalist evidence.

* * *

The abstraction becomes concrete in Kerala. In August 2018, the Indian state received its heaviest rainfall in nearly a century. In five weeks, 2,346 mm of rain fell — roughly twice the seasonal average. Eighty of the state's fifty-four rivers flooded simultaneously. More than four hundred and eighty dams reached capacity, and fourteen were opened for the first time in decades, sending sudden surges of water downstream into districts that were already submerged. Nearly five hundred people died. More than a million were evacuated to relief camps. The scale of the displacement overwhelmed the state's administrative capacity to locate and reach those in need.

Two instruments responded almost simultaneously, and their combination is worth examining carefully. ISRO's National Remote Sensing Centre activated its disaster management support protocol and began distributing near-daily satellite imagery of flood-inundated areas derived from Resourcesat-2, RISAT-1, and Sentinel-1 SAR data. The synthetic aperture radar imagery was particularly valuable: unlike optical sensors, SAR can penetrate cloud cover, and during a Kerala monsoon flood, cloud cover is total. The NRSC maps, updated every twenty-four to forty-eight hours, showed precisely which roads were submerged, which districts were still accessible, and where the water was advancing or retreating. They were distributed to district collectors, the Kerala State Disaster Management Authority, and the National Disaster Response Force. For responders planning evacuation routes and allocating boats, the maps were the difference between informed action and guesswork.

Simultaneously, a different network activated. The Humanitarian OpenStreetMap Team and the Kerala Disaster Relief volunteers launched a rapid mapping effort, tracing roads, identifying relief camps, and marking flooded zones onto OpenStreetMap using the same satellite imagery that NRSC was analysing. Indian volunteers — many of them students, many of them thousands of kilometres from Kerala — joined international contributors from the HOT community. Within days, the OSM base map of affected districts had been updated with information that official maps lacked: the location of each relief camp as it was established, the status of individual roads as they flooded and cleared, the GPS coordinates of isolated communities where rescue boats had not yet arrived.

What Kerala 2018 demonstrated is that the "Shift" in this book's framework is not a matter of changing individual minds about the political map. It is already happening at the operational level, in the decisions that disaster managers make when a monsoon breaks a state's infrastructure. In that moment, the question "which government claims sovereignty over this water?" becomes irrelevant. The question is: where is the water? Where are the people? What routes are still open? And those questions are answered not by the political map but by satellite imagery, by volunteer-traced road networks, by real-time geospatial data that does not know or care about the state boundary at Hogenakal. The Cauvery had crossed from Kerala into Tamil Nadu before the flood came. When the flood came, the response crossed those same boundaries — ISRO data, national disaster forces, international volunteers, and local knowledge operating together without a map in the old sense of the word. The physical reality of the crisis forced a view of the land that the political map had spent decades concealing: the river systems of Kerala and Tamil Nadu are one system, and when they flood, they flood together.

India's space programme did not set out to challenge territorial thinking. It set out to give India the ability to see its own land, to know its own rivers, to manage its own resources with its own instruments. That it achieved this is not in question. But in achieving it, it produced data whose logic runs ahead of the governance structures designed to use it. The ISRO flood maps of Kerala did not stop at the state boundary. The satellite that photographed the Periyar basin did not distinguish between the Kerala watershed and the Tamil Nadu watershed. The shift from national instrument to shared resource did not require a policy decision, or a treaty, or a change of government. It required a flood. And the flood, as floods do, showed the land as it actually is.

* * *

I began this book with a child colouring in a map. The map taught him that the world was made of coloured shapes, each sovereign, each separate. I am now, many chapters later, describing a set of instruments that were built to serve those coloured shapes but that, in the data they produce, show a world that is continuous, connected, and indifferent to the boundaries we have drawn. The shift is from the map to the image. From the claim to the measurement. From the coloured shape to the actual Earth.

India's space programme began with a rocket on a bicycle. It grew into a fleet of satellites that can see the subcontinent with sub-metre resolution. And the subcontinent it sees is not the coloured shape on the political map — it is a geological and hydrological and atmospheric reality that extends, without interruption, across every border that has been drawn through it. ISRO gave India the ability to see itself. What India does with that seeing —

whether it uses the data to deepen its sovereignty or to deepen its understanding of the systems it shares with its neighbours — is a choice that the satellite cannot make for us. But the data is there. It has been there for decades. And it is waiting for someone to use it not as a national asset but as a regional common.

The bicycle has become a satellite. The question is whether the satellite can become a bridge.

CHAPTER NINE

# The Obligation to See

I sit in front of a screen and I look at the Earth. This is my work. I have done it for years, and I expect to do it for years more, and if someone were to watch me doing it they would see nothing dramatic — a man at a desk, staring at a monitor, occasionally typing a command, occasionally writing a note, occasionally leaning forward to examine a pattern in the data that has caught his attention. It looks like office work. In a sense, it is office work. But the thing on the screen is the planet, and the patterns in the data are the signatures of what human beings are doing to it and to each other, and I have come to believe that seeing these things — having the instruments to see them, the training to interpret them, and the access to act on what they show — creates an obligation.

I do not use that word lightly. Scientists are trained to be cautious about moral claims. We are taught to describe, to measure, to analyse, to report — not to preach. The scientific paper ends with conclusions and recommendations for future research, not with calls to action. There is a good reason for this: the authority of science depends on its discipline, on its refusal to let passion distort evidence. I respect this discipline. I practise it in my own work. But I have also come to believe that discipline, taken too far, becomes a form of evasion. If I can see that a forest is being destroyed, and I can prove it with data that no one can dispute, and I say nothing because saying something feels like advocacy rather than science — then my discipline has become a shelter, and the shelter is comfortable, and the forest is still burning.

This chapter is about the obligation to see. Not the ability — that has been the subject of the preceding eight chapters. The ability is established. We have the instruments. We have the data. We have the archive, the algorithms, the platforms, the open-access policies, the volunteer networks, the citizen scientists, the national space programmes, the fifty-year record of reflected light from every landmass on the planet. The question is no longer whether we *can* see the Earth as it is. The question is what we owe the Earth, and each other, now that we can.

* * *

In an earlier chapter, I described the satellite as a witness — an instrument that records what happens on the ground without selection, without intent, without mercy. But the satellite does not interpret what it records. It does not write the report. It does not stand before the court and explain what the before-and-after images mean. It does not walk into the classroom and show the students what the false-colour composite reveals about the health of their river. The satellite sees, but it does not speak. That part falls to us — the scientists, the analysts, the researchers who know how to read the data and translate it into language that others can act on.

This makes the scientist a particular kind of witness. Not a bystander who happens to see something and is asked to testify. A trained observer, equipped with instruments, who has chosen to look. The choice matters. I chose to study remote sensing. I chose to learn how to read satellite imagery. I chose to spend my career looking at the Earth from above. And having made that choice, I cannot pretend that what I see does not carry implications, or that the implications are someone else's problem.

Consider what a geospatial scientist can see today. Deforestation in real time — the alert systems that flag forest loss within days of its occurrence. Glacier retreat measured in metres per year across the Himalayas. Urban sprawl consuming agricultural land on the outskirts of every major Indian city. Water bodies shrinking, coastlines eroding, temperatures rising, vegetation patterns shifting. All of this is visible in the data. All of it is documented in the archive. And all of it has consequences for the people who live on the land that is changing — people who, in many cases, cannot see the change from the ground because the change is too slow, or too large, or too distributed to be visible without the view from above.

The scientist sees what the citizen cannot. This is not a mark of superiority but a description of a division of labour. The farmer in the Thanjavur delta knows more about his soil than any satellite can tell me. The fisherman in the Sundarbans knows the rhythms of the tide better than any algorithm I could write. But neither of them can see the twenty-year trend in the data — the slow decline of the river's flow, the gradual intrusion of saltwater, the millimetre-by-millimetre rise of the sea. The scientist can. And if the scientist can see it and does not say it — does not publish it, does not explain it, does not make it available in a form that the farmer and the fisherman and the policymaker can use — then what is the science for?

* * *

There are many ways for a scientist to evade the obligation to see. I know them because I have practised some of them myself.

The first is specialisation. You retreat into your niche. You study the spectral properties of a particular crop, or the thermal behaviour of a particular urban surface, or the classification accuracy of a particular algorithm. Your papers are technical, your audience is other specialists, and the distance between your data and its human implications is maintained by the conventions of academic writing. You are not lying. You are not hiding anything. But you are also not connecting the dots, because connecting the dots would take you out of your specialisation and into questions that your training did not prepare you for.

The second evasion is objectivity. You tell yourself that the scientist's job is to produce data, not to interpret its moral significance. You say: I measure the rate of deforestation; it is for the policymaker to decide what to do about it. This sounds reasonable, and in certain contexts it is reasonable. But it can also become a way of washing your hands. The policymaker does not know how to read a Landsat composite. The journalist does not know the difference between NDVI and NDWI. If the scientist does not translate the data into a form that non-scientists can understand, the data sits in the archive and the forest continues to burn.

The third evasion is the most insidious: the belief that the data speaks for itself. It does not. Data is mute. It must be read, interpreted, contextualised, and communicated. A satellite image of a shrinking lake is not, by itself, a call to action. It becomes a call to action only when a human being says: this lake was here ten years ago, it is half the size now, here is why, and here is what will happen if the trend continues. The numbers require a voice, and the voice must belong to someone who understands what the numbers mean.

* * *

The moral argument is simple, and I will state it plainly. If you have the ability to see something that others cannot see, and the thing you see has consequences for the lives and wellbeing of other human beings, you have an obligation to make your seeing available to them. This is not a principle specific to geospatial science. It applies to any form of expertise that gives its holder knowledge that others lack and that others need. The doctor who sees a symptom that the patient cannot identify has an obligation to name it. The engineer who sees a structural flaw that the occupants cannot detect has an obligation to report it. The scientist who sees, in the data, a pattern that the public cannot perceive has an obligation to share it.

In geospatial science, this obligation has a particular character, because the things we see are not hidden by accident. They are hidden by scale. The deforestation is invisible from the ground because it is too large to see without altitude. The glacier retreat is invisible because it is too slow to see without a time-series. The border's arbitrariness is invisible because it has been naturalised by centuries of cartographic convention. The satellite does not reveal secrets. It reveals what is there, at a scale that the unaided human eye cannot access. And the scientist who works with the satellite is, in effect, the translator between the scale of the planet and the scale of the person.

I feel this obligation deeply. Not as a burden — I do not experience it as a weight that has been placed on me from outside. I feel it as a consequence of having seen. Once you have looked at the Earth from above — once you have seen the rivers that ignore borders, the forests that are disappearing, the cities that are growing into the farmland, the glaciers that are retreating year by year — you cannot un-see it. The knowledge changes you. It makes it impossible to look at a political map with the same innocence you had as a child. And it creates a responsibility that is, at bottom, very simple: if you have seen, you must say what you have seen.

* * *

I am not optimistic by temperament. This book has been, as I warned at the beginning, tinged with sadness — the sadness of a scientist who can see, in the data, how much damage territorial thinking has done to the Earth and to the relationships between the people who live on it. I see the Cauvery basin divided by a state boundary that the river does not recognise. I see the Indus basin managed as two separate systems by two countries that cannot agree to share a telephone call, let alone a river. I see the political maps that children are still colouring in — the same maps I coloured in, with the same crayons, teaching the same invisible lesson: the world is made of coloured shapes, and the shapes are real.

And yet I am not without hope. The hope is not in human nature, which I have found to be reliably territorial. The hope is in the instruments.

For the first time in the history of this species, we have machines in orbit that show us what the Earth actually looks like. Not what we have drawn on it. Not what we have claimed about it. Not what our governments tell us it looks like. What it actually looks like: continuous, connected, indifferent to our divisions, governed by physics rather than politics. This is a new thing in human experience. For three hundred thousand years, we saw the Earth from the ground — from inside the territory, looking outward, seeing neighbours as either friends or threats. Now we can see it from above. And from above, the neighbours are invisible. Only the land is there, and the water, and the weather, and the life that does not know it has been divided.

The shift I am asking for is not a political programme. It is a change in how we see. See the Earth before the map. See the watershed before the boundary. See the data before the claim. And once you have seen it, share what you see — with your students, your colleagues, your policymakers, your neighbours, anyone who will look. The satellite has given us a gift that no previous generation possessed: a view of our own planet that does not begin with the assumption that it is divided. Use it.

* * *

I began this book with a memory. A boy in a school in Tamil Nadu, filling in an empty political map with coloured pencils, learning without knowing it that the world was made of sovereign shapes. I have spent nine chapters trying to unsee what that map taught me — to describe, as clearly as I can, what the Earth looks like when you remove the colours and the lines and the claims of ownership and look at the ground itself.

What I have found, in a career spent looking at satellite imagery, is that the Earth does not look the way the map says it does. It looks like a single surface. Rivers flow across the boundaries we draw through them. Forests grow without reference to the sovereignty of the soil they root in. The monsoon delivers rain to India and Pakistan and

Bangladesh in a single, connected system that does not know it has been partitioned. The aquifer beneath the Punjab is one body of water, and the farmers on both sides of the border drink from it, and neither side's map acknowledges this fact.

Geospatial science did not create this reality. The reality has always been there, waiting for an instrument capable of seeing it. What geospatial science did was provide the instrument — and with the instrument, the evidence, and with the evidence, the obligation. We can now see the Earth as it is. We can share what we see with anyone who has an internet connection. And we can begin, if we choose, to shift our thinking from the map to the measurement, from the coloured shape to the continuous surface, from the border to the basin.

I do not know whether this shift will come in my lifetime. Territorial thinking is old, and deep, and reinforced by every political map on every classroom wall in every country on the planet. But the data is patient. The archive grows. Every sixteen days, Landsat passes over the same ground, asking the same question: *what is here?* Every day, volunteers add another road, another building, another clinic to the map that nobody owns. Every year, another country launches another satellite, and the satellite sees what satellites always see: a world without borders.

We are the only species that draws lines on the ground and then kills each other over them. We are also, as of the last fifty years, the only species that has built machines capable of showing us what the ground looks like without the lines. Both of these facts are true. The question of which one will matter more is not a question that science can answer. It is a question that we will answer, collectively, by what we choose to see and what we choose to ignore.

The lines are real. The suffering they cause is real. The wars fought over them are real. But the lines are not the Earth. The Earth is what the satellite shows us: one surface, one system, one planet. We drew the lines. We can learn to see past them.

# EPILOGUE

## The Pale Blue Dot

I began this book with a child filling in a blank map colouring the shapes, learning the names, absorbing without question the lesson that the world was made of sovereign territories. That child is still with me. I carry him into every satellite image I load, every dataset I open, every argument I make about the Earth's surface. He is why this book exists: because he was given one way of seeing, and spent the better part of his life trying to find another. This epilogue is an account of where that search has ended up, and what it has cost, and what it has found.

* * *

On 14 February 1990, the Voyager 1 spacecraft, having completed its primary mission and now drifting toward the edge of the solar system, turned its camera around and took one last photograph of Earth. The image, captured from a distance of approximately six billion kilometres, shows our planet as a single pale blue pixel, suspended in a beam of scattered sunlight. Carl Sagan, who had persuaded NASA to take the photograph, wrote about it afterwards with a sadness and a tenderness that I have never been able to read without feeling that he was speaking directly to me.

*Look again at that dot,* he wrote. *That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives... on a mote of dust suspended in a sunbeam.*

I have quoted Sagan because no one has said it better, and because the argument of this book arrives, at its end, at the same place his photograph did. We began on the ground, in a classroom in Tamil Nadu, colouring shapes on an empty map. We moved upward — to the altitude of Landsat, seven hundred and five kilometres, where the coloured shapes dissolve and the Earth appears as one continuous surface. And now, at the end, we move further still — to the edge of the solar system, where the entire planet shrinks to a fraction of a pixel, and the borders, the wars, the water disputes, the political maps, all of it becomes not merely invisible but inconceivable.

* * *

I have spent the chapters of this book making an argument in three parts. First, that the satellite shows us an Earth without borders — that the physical planet and the political planet are not the same thing, and that we have confused one for the other. Second, that when the tools of observation became free and open, something changed — ordinary people gained the ability to see the Earth for themselves, to map it, to submit its evidence in courts of law, to respond to disasters without waiting for permission from governments that may never grant it. Third, that this combination of seeing and sharing creates the possibility, though never the guarantee, of a shift in how we think about territory, sovereignty, and belonging.

I want to be honest about the limits of this argument. The shift I have described is not happening everywhere, and where it is happening, it is slow. Territorial thinking is not a fashion that will pass with the next generation; it is deeply embedded in law, in education, in the architecture of the state itself. Maps with coloured shapes will continue to hang in classrooms. Passports will continue to determine who may cross which line. Wars will continue to be fought over ground that, from orbit, looks no different on one side of the border than the other. I am not naive about any of this.

But I am also not willing to concede that nothing has changed. In 2008, an archive that governments had kept expensive became free, and within a decade twenty million scenes had been downloaded by researchers in a hundred and eighty countries. In 2010, six hundred volunteers mapped Port-au-Prince after the earthquake, and by 2023 that number had grown to twelve thousand for a single disaster. In 2016, the International Criminal Court accepted satellite evidence in a war crimes conviction for the first time in history. These are not metaphors for progress. They are facts. They are measurable. And they point, collectively, in a direction that I believe matters.

* * *

I think often about the boy I was, sitting in that classroom, colouring India with pride. I do not regret the pride. India is worth being proud of — its languages, its contradictions, its stubborn insistence on remaining one country when every reasonable prediction said it would splinter. What I regret is the assumption that followed the pride: that the coloured shape *was* the country. That the border defined the relationship. That the map told the truth.

The satellite told me a different truth. It told me that the Cauvery does not know it is crossing a state boundary. That the monsoon does not consult a map before deciding where to rain. That the soil in Punjab is the same soil on both sides of the Radcliffe Line, because the soil was there for millennia before Cyril Radcliffe arrived with his pen and his deadline and his ignorance of the land he was dividing. These are not political observations. They are physical facts, recorded in data, verifiable by anyone with an internet connection and the willingness to look.

I have tried, in this book, to follow the evidence where it leads. It has led me to an uncomfortable place — uncomfortable because the conclusion is not that borders are wrong, which would be simple, but that borders are *invented*, which is more difficult. An invented thing can be useful. An invented thing can be necessary. But an invented thing should never be mistaken for the ground itself. The moment we forget that we drew the lines, we begin to believe the lines drew themselves, and from that belief follows a chain of errors that has shaped, and misshaped, the modern world.

* * *

I am writing these final words in the same country where I coloured those maps. The classroom is different now; the maps are digital; the children can, if they choose, open a satellite image on a phone and see the Earth as it actually is. Whether they will choose to do so — whether their teachers will encourage them, whether their textbooks will acknowledge the difference between the political map and the physical planet — is not something I can control. But I can do what every scientist must eventually do, which is to say plainly what the evidence shows and then step aside.

The evidence shows a world without borders. Not a world that should be without borders — that is a political question, and I leave it to those who are better equipped to answer it — but a world that *is* without borders, physically, measurably, observably. The lines are ours. We drew them for reasons that made sense at the time, and some of those reasons still make sense. But the Earth does not know about our reasons. It continues, as it has always continued, as one surface, one system, one planet.

Sagan understood this. Standing at the edge of the solar system, looking back at a pale blue dot, he saw what the satellite shows us from a shorter distance: that there is no line on that dot. There is no border visible from six billion kilometres, just as there is no border visible from six hundred. The difference is only one of scale. The truth is the same.

We drew the lines. We can learn to see past them. And if enough of us do — if enough of us look at the satellite image and then look at the political map and notice the difference — then perhaps, slowly, the way we think about the Earth and about each other will begin to change. Not because someone commanded the change, but because we finally saw clearly.

That is the obligation. That is the hope. And that, for now, is enough.

# NOTES

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## Epilogue: The Pale Blue Dot

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# FIGURES AND TABLES

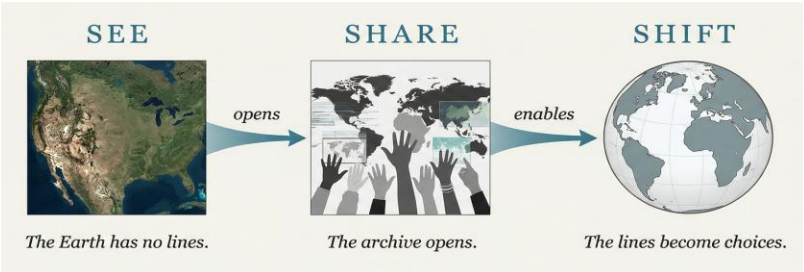


*Diagram A. The See/Share/Shift framework: the argumentative arc of this book.*

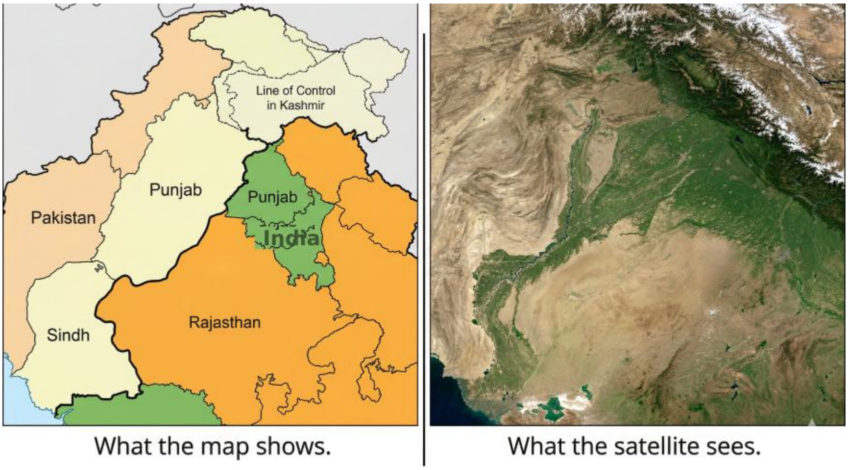

*Diagram B. The India-Pakistan border region: (left) political map; (right) satellite composite. The border visible on the map does not exist in the physical landscape.*

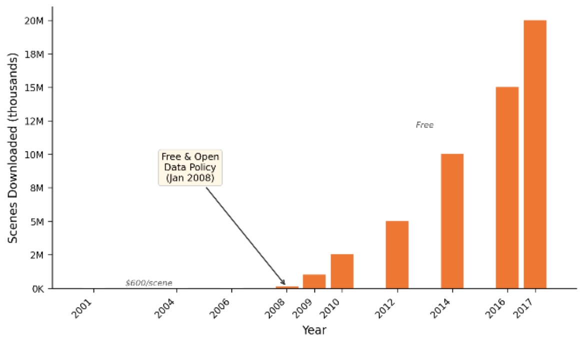


*Figure 1. Landsat scene downloads before and after the 2008 free and open data policy (USGS).*

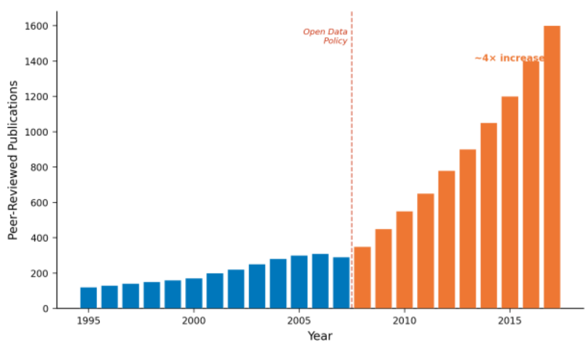


*Figure 2. Growth in peer-reviewed publications using Landsat data, 1995–2017.*

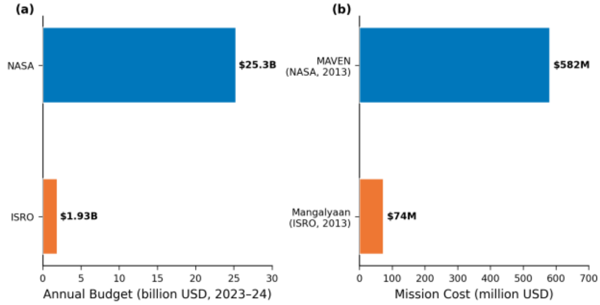


*Figure 3. ISRO and NASA: (a) annual budget comparison, 2023–24; (b) Mars mission cost comparison.*

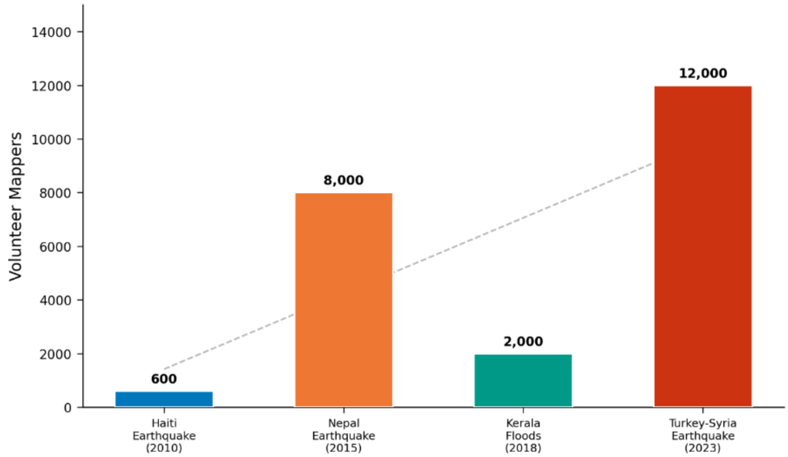


*Figure 4. Growth of OpenStreetMap volunteer response across major humanitarian disasters, 2010–2023.*

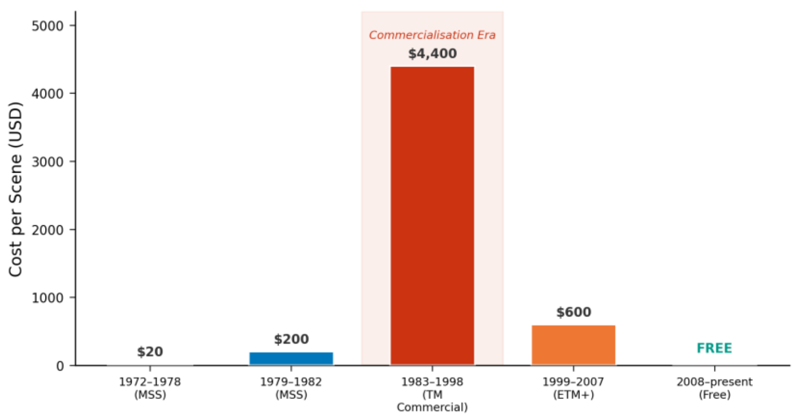


*Figure 5. Landsat scene pricing history, 1972–present.*

| Year | Event |
| --- | --- |
| 1569 | Mercator projection created for maritime navigation |
| 1648 | Treaty of Westphalia — origin of the modern state system |
| 1767 | Survey of India begins under the East India Company |
| 1895 | Mullaperiyar Dam built across the Periyar River, Kerala |
| 1947 | Radcliffe Line partitions India and Pakistan |
| 1960 | Indus Waters Treaty signed between India and Pakistan |
| 1962 | Vikram Sarabhai founds India's space programme |
| 1972 | Landsat 1 (ERTS-1) launched — Earth observation begins |
| 1988 | IRS-1A launched — India's first remote sensing satellite |
| 1991 | Anti-Tamil violence in Karnataka over Cauvery water |
| 2004 | OpenStreetMap founded by Steve Coast |
| 2005 | Cartosat-1 launched (2.5 m resolution) |
| 2008 | USGS makes Landsat archive free and open |
| 2010 | Haiti earthquake — OSM maps Port-au-Prince in 30 days |
| 2011 | Ethiopia begins Grand Ethiopian Renaissance Dam |
| 2013 | Mangalyaan launched to Mars ($74 million) |
| 2014 | Missing Maps project founded (Red Cross, MSF, HOT) |
| 2014 | ESA Sentinel-2 launches with free and open data policy |
| 2016 | ICC convicts al-Mahdi using satellite imagery evidence |
| 2019 | Cartosat-3 launched (sub-1 m resolution) |
| 2023 | Chandrayaan-3 lands on the Moon's south pole |

*Table 1. Key timeline of events in geospatial science and territorial governance.*

| River | Origin | Terminus | Length | Countries/States |
|---|---|---|---|---|
| **Cauvery** | Karnataka (Brahmagiri Hills | Tamil Nadu (Bay of Bengal) | 765 km | Karnataka, Tamil Nadu, Kerala, Puducherry |
| **Mullaperiyar/ Periyar** | Kerala (Western Ghats) | Diverted to Tamil Nadu | 244 km | Kerala, Tamil Nadu |
| **Indus** | Tibet (Mt. Kailash region) | Pakistan (Arabian Sea) | 3,180 km | China, India, Pakistan |
| **Nile** | Burundi/Rwanda (headwate Ethiopia (Blue Nile) | Egypt (Mediterranean) | 6,650 km | 11 countries |
| **Ganges** | India (Gangotri Glacier) | Bangladesh (Bay of Bengal | 2,525 km | India, Bangladesh |
| **Brahmaputra** | Tibet (Angsi Glacier) | Bangladesh (Bay of Bengal | 3,848 km | China, India, Bangladesh |

*Table 2. Major transboundary rivers discussed in this book.*