Research Unchained:
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A Special Issue of the Journal of Modern Slavery in collaboration with the Antislavery Early Research Project supported by the AHRC Antislavery Usable Past

Analysing Slavery through Satellite Technology: How Remote Sensing Could Revolutionise Data Collection to Help End Modern Slavery

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Volume 4, Issue 2
December 2018

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Acknowledgements

The authors would like to thank the Rights Lab for providing funding for the lead author's research and the Anti-Slavery Usable Past Postgrad Research Network (ASUP PGRN), now the Antislavery Early Research Association, for inviting submissions for the special issue following the Workshop held in Liverpool in 2017. We would also like to thank the reviewers for all of their constructive feedback. The authors would like to acknowledge that they have written the piece from the starting point as non-survivors.

Abstract

An estimated 40.3 million people are enslaved globally across a range of industries. Whilst these industries are known, their scale can hinder the fight against slavery. Some industries using slave labour are visible in satellite imagery, including mining, brick kilns, fishing and shrimp farming. Satellite data can provide supplementary details for large scales which cannot be easily gathered on the ground. This paper reviews previous uses of remote sensing in the humanitarian and human rights sectors and demonstrates how Earth Observation as a methodology can be applied to help achieve the United Nations Sustainable Development Goal target 8.7.

Key words: Crowdsourcing; Modern Slavery; Remote Sensing; Satellites; Sustainable Development Goals.

Analysing Slavery through Satellite Technology: How Remote Sensing Could Revolutionise Data Collection to Help End Modern Slavery

Globally an estimated 40.3 million people are currently trapped in modern slavery, a quarter of whom are children.[1] To tackle slavery, and a number of other developmental challenges, the United Nations (UN) created the Sustainable Development Goals (SDGs), which came into force on 1 January 2016, replacing the Millennium Development Goals (MDGs).[2] The MDGs aimed to remove people

[1] This figure was first estimated in 2017 when the International Labour Organisation (ILO) partnered with Walk Free, the producers of the Global Slavery Index (GSI). The figure is the most current estimate available, and was determined using surveys, interviews and datasets. The global estimate was first produced for the 'Global Estimates of Modern Slavery' report published by the ILO. These results were then expanded upon in the 2018 edition of the 'Global Slavery Index' which provides a breakdown of the figures by country. However, there are a number of critiques of the GSI approach, particularly regarding the methodologies used in the Index and the alterations of the definition of 'modern slavery' used within each edition (Guth *et al*. 2014; Gallagher 2017; Mügge 2017). The term 'modern slavery' is used throughout as it is the overarching term found within the United Kingdom's legislation regarding slavery, the *Modern Slavery Act* 2015 (http://www.legislation.gov.uk/ukpga/2015/30/contents). Whilst it must be acknowledged that there are a number of valid reasons against the use of this term, many of which are outlined by Michael Dottridge (2017), the widespread use of the term 'modern slavery' and the nature of exploitation described in the *Modern Slavery Act* 2015 was deemed appropriate for this manuscript. Walk Free Foundation and International Labour Organisation. "Global Estimates of Modern Slavery: Forced Labour and Forced Marriage." Geneva, 2017; ———. "Global Estimates of Child Labour: Results and Trends, 2012-2016." Geneva, 2017; Walk Free Foundation. "The Global Slavery Index 2018." Australia, 2018.

[2] World Bank and UNDP. "Transitioning from the MDGs to the SDGs." New York, 2015.

from situations of poverty, whereas the SDGs aim to provide an environment that will keep them out of poverty for good. The remote sensing community has long worked to tackle issues within the SDGs, primarily those related to the environment. However, an increasing number of applications relate to targets and indicators that have social and cultural implications for sustainability across a number of fields.[3] One target that could benefit from the use of geospatial information, is target 8.7 (part of SDG 8), which aims to tackle forms of modern slavery and child labour. Target 8.7 stipulates society must:

> Take immediate and effective measures to eradicate forced labour, end modern slavery and human trafficking… and by 2025 end child labour in all its forms.[4]

With the goal firmly set, governments, businesses and campaigners have joined the fourth anti-slavery movement to help eradicate slavery for good.[5] However, technological advancements for data collection on modern slavery could hold the key to end this fight.

The use of satellite imagery for tackling the SDGs is a recent and growing phenomenon.[6] Katherine Anderson et al. explored a range of possible uses for remote sensing technology and the SDGs, of which many examples touched upon the impact of changing environmental indicators and the effect that changes in ecosystems, climate variables and—in the most human orientated analysis—population exhibit.[7] These examples barely touched on Goal 8, only briefly mentioning other economic indicators within the goal but never explicitly referring to target 8.7. Moreover, the use of remote sensing exploring cultural heritage has been examined.[8] The work by Wen Xiao *et al*. is built upon a range of studies that had developed methods to investigate archaeological sites using remotely sensed

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[3] Qihao Weng. *Remote Sensing for Sustainability*. CRC Press: Boca Raton, 2016.

[4] "Sustainable Development Goal 8." Sustainable Development Knowledge Platform, United Nations, accessed May 18, 2017, https://sustainabledevelopment.un.org/sdg8

[5] The fourth anti-slavery movement is one of the key factors driving the current academic scholarship and developments in anti-slavery community present today: see Zoe Trodd. "Introducing the Rights Lab." University of Nottingham, accessed August 20, 2018, http://blogs.nottingham.ac.uk/rights/2017/08/04/walkfree7/; and "The Antislavery Usable Past." Arts & Humanities Research Council, accessed August 20, 2018, https://ahrc.ukri.org/research/casestudies/the-antislavery-usable-past/.

[6] John Trinder, Sisi Zlatanova, and Jie Jiang. "Editorial to Theme Section on UN Sustainable Development Goals (SDG)." *ISPRS Journal of Photogrammetry and Remote Sensing* 142 (2018):342-343.

[7] Katherine Anderson *et al*. "Earth Observation in Service of the 2030 Agenda for Sustainable Development." *Geo-spatial Information Science* 20, no. 2 (2017):77-96.

[8] Wen Xiao *et al*. "Geoinformatics for the Conservation and Promotion of Cultural Heritage in Support of the UN Sustainable Development Goals." *ISPRS Journal of Photogrammetry and Remote Sensing* 142 (2018):389-406.

data, which are commonly conducted using radar, LiDAR and imagery analysis from Unmanned Aerial Vehicles (UAVs) or satellite imagery. Their study impressed the importance of these methods in the context of supporting elements of both SDG 8 and SDG 11 which both include references to cultural heritage. Overall, Xiao *et al*.'s study demonstrates the benefit of remote sensing technology to protect cultural heritage, and suggests where such technology can be used in the future. The studies mentioned above show a clear movement in the remote sensing field to research which supports the SDGs and the associated 169 indicators.

While there is a limited amount of information referring to geospatial technology and the SDGs, there have been many uses of remote sensing for humanitarian and human rights research and practice, with new innovations in the types of data used for analysis.[9] Non-governmental organisations (NGOs) are beginning to invest in the use of these technologies to tackle human rights violations, for example, Amnesty Decoders.[10] The development of these uses represents an important step towards the use of remote sensing technology for social challenges.

Remote Sensing for Humanitarian and Human Rights Cases

Remote sensing is the practice of collecting data predominantly passively (using reflected sunlight from the Earth's surface to measure the reflectance of features on the ground to determine their properties) from a distance. Since the first satellite was launched in the 1950s, capabilities to monitor the Earth have continued to develop. There were more than 600 earth observation (EO) and earth science satellites orbiting the planet in 2017 collecting large volumes of data with untapped potential to investigate industries, known to be utilising modern slavery practices, from above.[11] There are large temporal sets of data, for instance, the U.S. Landsat mission. The data from this mission was made freely available in 2008, providing an archive of imagery spanning more than 40 years.[12] The Landsat missions have a medium spatial resolution (30m pixels), allowing for vast data collection at a reasonable level of detail across the entire planet. However, the

[9] Naomi Larsson. "How satellites are being used to expose human rights abuses." *The Guardian*, accessed May 19, 2018, https://www.theguardian.com/global-development-professionals-network/2016/apr/04/how-satellites-are-being-used-to-expose-human-rights-abuses; Robin Pierro, Tom Walker and Ben Davis. "Satellite Imagery for Human Rights Monitoring." *The Engine Room*, accessed May 19, 2018, http://library.theengineroom.org/satellite-imagery-human-rights/.

[10] "Amnesty Decoders." Amnesty International, accessed May 18, 2018, https://decoders.amnesty.org/.

[11] Union of Concerned Scientists. "UCS Satellite Database." 2017.

[12] Mariel Borowitz, *Open Space: The Global Effort for Open Access to Environmental Satellite Data.* London: MIT Press, 2017.

continuing availability of the imagery is uncertain.[13] Other satellites, with even higher resolutions, allow us to view features on the Earth's surface in detail, such as DigitalGlobe, a commercial satellite imagery provider. Increasingly data are improving in all resolutions – source (as in laser, radar, optical), spatial (different pixels sizes), spectral (different wavebands), temporal (collected on different dates) and radiometric (data content of the pixel). Data are also becoming free at the point of access, particularly from satellites owned and operated by national space agencies; greatly increasing the range of possible uses.

Remote sensing comes from three primary platforms: UAVs, airborne (for instance planes), and satellites. In the fight against modern slavery it is satellite imagery that is the most appropriate, not only because of the vast abundance of imagery, but also for two other key reasons. First, it provides detail which is cost-effective compared to launch, collection and processing costs. Second, it protects vulnerable people's privacy should they be enslaved because they are not visible at the spatial resolutions available. Coarser imagery, such as those which are available freely, are therefore beneficial as they prevent slaveholders from identifying workers and locations which may lead them to take harmful actions, impacting on those who are enslaved. Cost-effective, open access, data affords NGOs, academics and policy makers the opportunity to conduct analysis with a focus on modern slavery. Monitoring cases of human rights violations and humanitarian crises with remotely sensed data have become common, however, these platforms have never been used within the modern anti-slavery movement.[14]

UAVs, a recent technological development, have taken the practice of remote sensing to the mainstream. However, imagery collected from the small cameras placed on board (known as the payload) have primarily been used in humanitarian cases; such as in disaster hit areas to help develop clear plans for delivering aid and assessing damage within remote areas before aid workers arrive.[15] When a camera is situated in the payload imagery can be captured and has been used in a number of contexts. For example, refugee camps have grown large in number and size across the Middle East, particularly since the start of the Syrian conflict in 2011. Satellite imagery has revealed rapid expansion of the UN's refugee camps and can help to protect those within the camp in conflict

[13] Gabriel Popkin. "US government considers charging for popular Earth-observing data." *Nature* 556 (2018): 417-418.

[14] AAAS. "Human Rights Applications of Remote Sensing: Case Studies from the Geospatial Technologies and Human Rights Project." Washington DC, 2014.

[15] Kalev Leetaru. "How Drones Are Changing Humanitarian Disaster Response." *Forbes*, accessed May 18, 2018, https://www.forbes.com/sites/kalevleetaru/2015/11/09/how-drones-are-changing-humanitarian-disaster-response/#6a39b3a0310c.

situations.[16] Despite the registration process upon entering a camp, population monitoring can be difficult, and analysis of data collected by an on board UAV camera, or a satellite image, can provide a more accurate estimation of the number of residents, thus assisting registrars on the ground. These methods use tents and shelters to estimate the number of people present which is vital as it informs the volume and scale of provisions required for each camp.[17]

Whilst the use of UAVs may be beneficial in some contexts they may not be for all. UAVs fly close to the ground, thus they can capture a lot of detailed images; features such as people and vehicles are visible. Airborne sensors fly higher, but they also carry sensors which may put people at risk, these features are also becoming common in commercial satellite data. For example DigitalGlobe's 'WorldView' satellites have a spatial resolution of up to 31cm (high enough to view and detect the model of a car, but not so high as to identify people) which is available commercially for the first time since changes to U.S. law.[18] It is therefore important to consider the ethics of using remote sensing for a human rights issue such as modern slavery, as high levels of detail in the future may put vulnerable people at risk of further harm. There is no guarantee that imagery will not be used nefariously, however, these high resolution data are still primarily commercial, limiting those who can access the data to those who have the financial means, or are restricted by governments.[19] The technology is already available and there appears to be very little will to restrict access again, but perhaps imagery providers need to consider who the data are released to and users must also play a role in thinking carefully about what data are required, and why, when engaging in remote sensing investigations of vulnerable populations.

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[16] Joe Belliveau. "Humanitarian Access and Technology: Opportunities and Applications.". *Procedia Engineering* 159 (2016):300-306.

[17] Francesco Checchi, Barclay T. Stewart, Jennifer J. Palmer, and Chris Grundy. "Validity and Feasibility of a Satellite Imagery-Based Method for Rapid Estimation of Displaced Populations." *International Journal of Health Geographics* 12, no. 1 (2013):4; Stefan Lang *et al*. "Earth-Observation (EO)-based *ex post* assessment of internally displaced person (IDP) camp evolution and population dynamics in Zam Zam, Darfur." *International Journal of Remote Sensing* 21, no. 21 (2010):5709-5731; Patrick Meier. "The First Ever 3D Model of a Refugee Camp Made with UAV Imagery." *iRevolutions*, accessed May 4, 2018, https://irevolutions.org/2015/08/17/first-3d-model-refugee-camp/.

[18] Michael Koziol. "Lifting restrictions on satellite imagery means even closer close-ups from space." *The Sydney Morning Herald*, accessed December 4, 2018, https://www.smh.com.au/technology/lifting-restrictions-on-satellite-imagery-means-even-closer-closeups-from-space-20140618-zsdh1.html.

[19] Ann M. Florini, and Yahya Dehqanzada. "Commercial Satellite Imagery Comes of Age." *Issues in Science and Technology* XVI, no. 1 (1999).

Ethical Considerations

The ethics of remote sensing have been considered since the first high spatial resolution satellite was launched in the 1990s. More recently Tanya Notley and Camellia Webb-Gannon have explored the issues of remote sensing and privacy with special reference to the application of remote sensing for human rights analysis.[20] There are a number of concerns about the use of satellite imagery for tackling human rights violations, including slavery. NGOs do not want to endanger vulnerable people should cases of slavery be identified, and the slaveholders somehow become aware of this. Concerns such as these should be considered within all remote sensing analysis that aims to protect people from human rights abuses. The community of analysts and NGOs must be aware of the possible risks to those they are trying to help, to protect them from further harm. Similar ethical considerations have been noted with reference to required regulations that prevent the marginalisation and targeting of vulnerable groups within society.[21] This idea is considered further by Austin Choi-Fitzpatrick who argues that researchers and organisations using UAVs to enable societal change for good need to prioritise six key concepts: subsidiarity, physical and material security, the 'do no harm' principle (balancing the situation being monitored and the risks involved to those producing, using and featured within the data collected), the public good, respect for privacy and respect for data.[22] It is important that a strict code of ethics, common in the field of remote sensing and study of modern slavery, is adhered to in order to mitigate risk of further distress, harm or violation to enslaved workers through the use of the technology—bearing in mind the 'do no harm' aspect of the work.

Some of the issues of privacy may also apply to very high spatial resolution satellite imagery. The sensors that supply this type of data tend to be commercially owned and therefore the data can be extremely expensive. This is where tradeoffs regarding satellite data selection are often made. In the case of investigating industries using modern slavery practices, the most vital consideration is the protection of vulnerable populations, these must also be considered alongside costs and the level of detail needed within the imagery in order to conduct meaningful analysis. Whilst the majority of open-source data have pixel resolutions of around

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[20] E. Terrence Slonecker, Denice M. Shaw, and Thomas M. Lillesand. "Emerging Legal and Ethical Issues in Advanced Remote Sensing Technology." *Photogrammetric Engineering and Remote Sensing* 64, no. 6 (1998):7; Tanya Notley, and Camellia Webb-Gannon. "Visual Evidence from Above: Assessing the Value of Earth Observation Satellites for Supporting Human Rights." *The Fibreculture Journal* 3, no. 27 (2016).

[21] R.L. Finn, and D. Wright. "Unmanned aircraft systems: Surveillance, ethics and privacy in civil applications." *Computer Law and Security Review* 28 (2012):184-194.

[22] Austin Choi-Fitzpatrick. "Drones for Good: Technological Innovations, Social Movements, and the State." *Journal of International Affairs* 68, no. 1 (2014):19-36.

30m, the new European Space Agency (ESA) Copernicus programme's Sentinel-2 satellites have 10m spatial resolution and a revisit rate of 5 days; these pixels are still large enough, however, to diminish the risk of privacy violations.[23] Consequently, satellite imagery is seen as the most applicable form of data to help analyse practices of modern slavery.

Remote Sensing Modern Slavery

There is precedent for the use of remote sensing in a range of human rights applications but there has not been a concerted effort to apply these practices to instances of modern slavery.[24] The idea for using satellite imagery in the effort to measure and end slavery was first mooted by Kevin Bales when visiting the UN's Office for Outer Space Affairs (UNOOSA).[25] He recognised how satellite technology could help to target the remotest of areas where slavery often takes place. This is an important benefit as imagery can help support anti-slavery NGOs on the ground by providing detailed maps of industries in remote areas which may have previously been inaccessible, or even unknown. Although remote sensing methods may not be applicable to collect data on all types of slavery, the use of remotely sensed imagery provides an additional resource to enhance understanding of numerous industries. However, this does not mean the method will replace interactions with survivors and organisations on the ground working to end slavery; the view would be to create additional avenues of data collection alongside these established techniques. Industries where satellite imagery would be applicable include: brick kilns (see Figure 1), quarries, mines, charcoal camps, fish-processing camps and fishing (in both open water and oceans). The problem of modern slavery is so widespread and the collection of remotely sensed imagery is so frequent, that the technology would be beneficial as an additional methodological tool to use in this field.

Satellites and Slavery in Academia

At the time of writing only one published research paper has used remotely sensed imagery to provide information on slavery within an academic setting, but there has been a growth in the number of studies specifically investigating modern

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[23] ESA. "Sentinel-2 User Handbook." *European Commission*, 2015; M. Drusch *et al.* "Sentinel-2: Esa's Optical High-Resolution Mission for GMES Operational Services." *Remote Sensing of Environment* 120 (2012):25-36.

[24] AAAS. "Human Rights Applications of Remote Sensing: Case Studies from the Geospatial Technologies and Human Rights Project."

[25] Kevin Bales. *Ending slavery: how we free today's slaves*. Berkeley, CA: University of California Press, 2007:163-164.

slavery.[26] Doreen Boyd *et al*. estimated the number of brick kilns in South Asia using open source imagery available through Google Earth Pro.[27] This is an important piece of research as it assesses an industry that is known to use bonded and child labour. Previously, little was known about the extent of the South Asian brick manufacturing industry, and the development of this estimate would not have been possible without geospatial technology due to the size of the region being investigated. The work by Boyd *et al*. is a beneficial development in the possible use of technology for human rights analysis but is also important for NGOs and local governments, as the information can be used to help with the decision-making process when abolishing slavery practices within brick manufacturing.[28] Moreover, the study embraces crowdsourcing to collect data and demonstrates the engagement of civil society with the SDGs—which is key to ensuring they are sustained and successful—as well as processing large volumes of data quickly.

Building on this, researchers at the University of Nottingham have begun to investigate the impact of illegal fish-processing camps within the UN Educational, Scientific and Cultural Organization (UNESCO) protected Sundarbans Reserve Forest, Bangladesh (Figure 2).[29] These sites are known to use child labour.[30] They are also understood to have an adverse impact on the mangroves in which they are situated. Geospatial technology in this case can be used to protect the environment and help to support the liberation of enslaved workers through the provision of evidence to encourage government and UN-led action.

The Slavery-Environment Nexus in Research

Satellites are used extensively to monitor the Earth System's environment, providing a robust and continuous method to measure and monitor our anthropogenic footprint.[31] The knowledge acquired through the analysis of satellite

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[26] Details of research on modern slavery occurring within the UK are available through a database supported by the Independent Anti-Slavery Commissioner and the University of Nottingham's Rights Lab; the database is accessible via http://iascresearch.nottingham.ac.uk/

[27] Doreen S. Boyd *et al*. "Slavery from Space: Demonstrating the role for satellite remote sensing to inform evidence-based action related to UN SDG number 8." *ISPRS Journal of Photogrammetry and Remote Sensing* 142 (2018):380-388.

[28] *Ibid*.

[29] Cara McGoogan and Muktadir Rashid. "Satellites reveal 'child slave camps' in UNESCO-protected park in Bangladesh." *The Telegraph*, accessed October 26, 2016, https://www.telegraph.co.uk/technology/2016/10/23/satellites-reveal-child-slave-camps-in-unesco-protected-park-in/.

[30] Kari B. Jensen "Child Slavery and the Fish Processing Industry in Bangladesh." *Focus on Geography* 56, no. 2 (2013):54-65.

[31] Andrew J. Tatum, Scott J. Goetz and Simon I. Hay. "Fifty Years of Earth Observation Satellites." *Am Sci.* 96, no. 5 (2008):390-398.

imagery provides data to manage the environment, limit damaging actions, and establish measures of the relative successes, or failures, of environmental policies which have been employed to mitigate damage. The environmental destruction of our planet is documented daily by EO satellites, creating an extensive and valuable archive of data. These data are used to inform practice and improve environmental awareness, but the question remains, how may they also be used to assist in the eradication of modern slavery.

The destruction of the environment and the presence of modern slavery are entwined in a 'deadly dance'.[32] Those subject to debt bondage or forced labour are often involved in dangerous and destructive practices that have the potential to etch large physical signatures upon the landscape; deforestation of the Amazon is a clear example of this.[33] If modern slavery were a country it would be the third largest emitter of carbon dioxide (CO_2) globally, yet, little emphasis has been placed on the study of the powerful linkage between such social and physical variables.[34] Common debt bonded labours with high environmental impacts include forestries, fisheries, factories and farming.[35]

The brick kiln industry is widespread across South Asia, as discussed previously, but the true scale of the environmental impacts have not yet been realised. At present, the volume of emissions have been explored, as has the extraction of clay, used to produce the bricks, which strips the land reducing the fertility thus pushing those reliant on agriculture into further vulnerability.[36] Similarly, mining releases a variety of heavy metals via the extraction of particular ores; Mercury is common across Gold mining in West Africa and South America.[37] Planet satellites, for example, have captured evidence of extensive gold mining in

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[32] Bales. *Blood and Earth: Modern Slavery, Ecocide and the Secret to Saving the World*. New York: Speigel & Grau, 2016.

[33] Philip M. Fearnside. "The Roles and Movements of Actors in the Deforestation of Brazilian Amazonia." *Ecology and Society* 13, no. 1 (2008):23.

[34] Bales. *Blood and Earth: Modern Slavery, Ecocide and the Secret to Saving the World.*

[35] Doreen Boyd *et al.* "Modern Slavery, Environmental Destruction and Climate Change: Fisheries, Field, Forests and Factories." Rights Lab, University of Nottingham, Royal Holloway University of London and IASC, 2018.

[36] Boyd *et al*. "Slavery from Space: Demonstrating the role for satellite remote sensing to inform evidence-based action related to UN SDG number 8."; Bhat Mohd Skinder, Afeefa Qayoom Sheikh, Ashok K. Pandit and Bashir Ahmad Ganai. "Brick kiln emissions and its environmental impact: A Review." *Journal of Ecology and the Natural Environment* 6, no. 1 (2014):1-11; Bhat M Skinder *et al*. "Effect of brick kiln emissions on commonly used vegetables of Kashmir Valley." *Food Science and Nutrition* 3, no. 6 (2015):604-611; Suman Kumar Pariyar, Tapash Das and Tanima Ferdous. "Environment and Health Impact for Brick Kilns in Kathmandu Valley." *International Journal of Scientific & Technology Research* 2, no. 6 (2013):184-187.

[37] Martin J. Clifford. "Assessing releases of mercury from small-scale gold mining sites in Ghana." *The Extractive Industries and Society* 4, no. 3 (2017):497-505; Jacqueline R. Gerson, Charles T. Driscoll, Heileen Hsu-Kim and Emily S. Bernhardt. "Senegalese artisanal gold mining leads to elevated total mercury and methylmercury concentrations in soils, sediments, and rivers." *Elementa Science of the Anthropocene* 6, no. 1 (2018):11.

Peru.[38] Elsewhere, Mercury can have devastating health effects, and in the Eastern Congo, illegal mining impacts water quality, increases deforestation and contributes to poaching.[39] The environmental damage caused by industries known to heavily use modern slavery practices are perpetuating a socially and ecologically damaging cycle, increasing the risk of populations becoming vulnerable to enslavement.

Shrimp farms and fish-processing camps in the Sundarbans use slave labour to remove coastal mangroves, as discussed above.[40] These forests are a globally important carbon sink, and a key defence against erosion and natural disasters.[41] The cyclicity between human vulnerability and its exploitation, and environmental vulnerability and its exploitation, continues to be exacerbated. In Brazil, the agricultural industry plays a large role for those living in modern slavery. Illegal deforestation for logging and cattle ranch land clearance are common, despite tough anti-slavery laws and the climate protection offered by the rainforest.[42] There is growing evidence of a modern slavery-environmental destruction nexus. Exploring the interactions between the two is important not only to preserve the environment from serious threats such as climate change, but also protect those at risk of modern slavery.

These examples demonstrate synergies within environmental signatures that have the potential to be located in remote sensing imagery. Primary visual signatures such as the shapes and patterns of industries, and secondary signatures held within the environment can be explored. Visual signals for instance include the distinct oval kilns and rows of drying bricks in the 'Brick Belt'.[43] Whereas secondary signatures can include land-use change, alteration of vegetation health and flood frequencies, among others.[44] Remote sensing technology is already

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[38] Planet Labs. "Illegal Mining in Peru." *Planet*, accessed December 6, 2018, https://www.planet.com/gallery/mining-peru/.

[39] Carlos Salazar-Camacho *et al*. "Dietary human exposure to mercury in two artisanal small-scale gold mining communities of northwestern Colombia." *Environmental International* 107 (2017):47-54; Bales. *Blood and Earth: Modern Slavery, Ecocide and the Secret to Saving the World*.

[40] *Ibid*.

[41] L.G. Gillis, E.F. Belshe and G.R. Narayan. "Deforested Mangroves Affect the Potential for Carbon Linkages between Connected Ecosystems." *Estuaries and Coasts* 40, no. 4 (2017):1207-1213; Bales. *Blood and Earth: Modern Slavery, Ecocide and the Secret to Saving the World*.

[42] Brazilian Penal Code. "Article 149: Reduction to Condition Analogous to Slavery." Brasília, 2003.

[43] Boyd *et al*. "Slavery from Space: Demonstrating the role for satellite remote sensing to inform evidence-based action related to UN SDG number 8."

[44] Laura J. Sonter *et al*. "Mining drives extensive deforestation in the Brazilian Amazon." *Nature Communications* 8 (2017):1013; Chandra Giri. "Observation and Monitoring of Mangrove Forests Using Remote Sensing: Opportunities and Challenges." *Remote Sensing* 8, no. 9 (2016):783; G.M. Foody. "Remote sensing of tropical forest environments: Towards the monitoring of environmental resources for sustainable development." *International Journal of Remote Sensing* 24, no. 20 (2003):4035-4046.

capable of detecting many of these signatures at differing scales. Satellite imagery provides a unique line of enquiry, with remote sensing methodologies enabling evidence-based decisions for both social and environmental science policy. Indeed, such cross disciplinary projects are beginning to explore these themes.[45] Projects at Stanford University are utilizing remote sensing imagery to assess the environmental output of brick kiln pollution in Bangladesh, and the University of Nottingham's Rights Lab has investment in the field with their 'Data Programme', researching the uses of remote sensing to measure modern slavery and assess its impact on the Earth's environmental systems.[46]

The link between climate change, poverty and forced labour is well documented, yet the ability to conduct local analyses efficiently to provide action to limit the impacts of these issues is poor due to the remoteness of locations, lack of resources and limited enforcement of laws to protect people and the environment – satellites can be used to identify these potential vulnerabilities, prior to entrapment.[47] By highlighting spatial patterns and causal variables at high temporal resolutions, remote sensing allows the development of monitoring programmes. For Cambodia – ranked second in the list of climate vulnerable countries – the relationship between changing work opportunities, due to climate forced landscape alterations, and migration, which often leads to debt bondage, is closely studied.[48] The Blood Bricks project is one such study that is examining how climate change is facilitating modern slavery.[49] The combination of local ground intelligence, coupled with analysis of satellite imagery showing environmental change provides a powerful opportunity to analyse spatial, physical and human pressures which may increase vulnerability. It is possible to use satellites to both understand past patterns and model future modern slavery-environmental destruction scenarios so support can be provided to strengthen security and reduce vulnerability across these regions.

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[45] Such as Royal Holloway's Blood Bricks project (www.projectbloodbricks.org/project) and the University of Nottingham's Rights Lab (http://rightsandjustice.nottingham.ac.uk/).

[46] Rob Jordan. "Stanford researchers team up to reduce pollution and improve health." *Stanford News*, accessed May 16, 2018, https://news.stanford.edu/2017/09/14/stanford-researchers-team-reduce-pollution-improve-health/; Rights Lab. "Data Programme." *University of Nottingham*, accessed December 4, 2018, https://www.nottingham.ac.uk/research/beacons-of-excellence/rights-lab/programmes/data/index.aspx; Todd Landman. "Out of the Shadows: Trans-disciplinary Research on Modern Slavery." *Peace Human Rights Governance* 2, no. 2 (2018):143-162.

[47] Mike Kaye and Aidan McQuade. "Poverty, Development and the Elimination of Slavery." *Anti-Slavery International*. London, 2007.

[48] K. Brickell, L. Parsons, N. Natarajan and S. Chann. "Blood Bricks: Untold Stories of Modern Slavery and Climate Change from Cambodia." Royal Holloway University of London, 2018; Blood Bricks. "The climate change-modern slavery nexus: Why study Cambodia?" *Royal Holloway University*, accessed May 18, 2018, https://www.projectbloodbricks.org/blog/2017/7/19/blood-bricks-on-the-intersection-of-climate-change-and-modern-slavery.

[49] *Ibid.; Ibid.*

Documenting the scale of these environmental impacts are the first steps in being able to evaluate the damaging contribution of modern slavery on the environment. With space agencies continually responding to the demand for satellite data to monitor Earth's environment, advances in sensor design and delivery of knowledge products (that enable a user to easily access information); there is no reason to believe that a satellite derived 'Geospatial Environmental Slavery Index' product would not be achievable which could support the end of modern slavery, alongside a number of environmental SDGs.

Further Developments in Academia

Work undertaken at the Harvard Humanitarian Initiative (HHI) with the Satellite Sentinel Project (SSP) combines evidence from satellite imagery and witness testimony, to draw together details to assess humanitarian crises and human rights violations.[50] The HHI is one of the leading academic institutions looking at the way new data technologies can support humanitarian work. This was demonstrated successfully when SSP collaborated with DigitalGlobe to assess the impacts of the Sudanese conflict.[51] Piecing together multiple analysis methods allows NGOs to create a holistic story surrounding an event.[52] Although these studies do not specifically relate to modern slavery, the humanitarian crises analysed by the HHI and SSP contain risk factors that may lead to increased vulnerability to enslavement.[53] Poverty can often lead to enslavement, which can be impacted by disasters, conflict and population growth.[54] Many of these risks overlap with the work of humanitarian agencies.

Combining multiple data acquisition methods is something academics should consider for the study of modern slavery going forward. Remote sensing techniques are producing an increasing volume of data, which can be used alongside a myriad of other sources – including survivor testimony, supply chain analysis, and survey data - to refine global estimates of modern slavery. Additional benefits from satellite imagery may include locational analysis of industries known to use an enslaved workforce. By combining data sources the exact locations of

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[50] Brittany L. Card and Isaac L. Baker. "GRID: A Methodology Integrating Witness Testimony and Satellite Imagery Analysis for Documenting Alleged Mass Atrocities." *Genocide Studies and Prevention: An International Journal* 8, no. 3 (2014):49-61.

[51] The Enough Project and Satellite Sentinel Project. "Architects of Atrocity." Washington DC, 2013.

[52] For example Forensic Architecture https://www.forensic-architecture.org/.

[53] Kevin Bales. *Understanding Global Slavery: A Reader*. Berkeley, CA: University of California Press, 2005.

[54] Kaye and McQuade. "Poverty, Development and the Elimination of Slavery." London, 2007; Kevin Bales "How to combat modern slavery." *TED*, accessed September 9, 2018, https://www.ted.com/talks/kevin_bales_how_to_combat_modern_slavery/.

modern slavery activity may be identified. Despite the field being in its infancy, using satellite imagery to track slave-based industries within academia is an important step in the effort to end slavery by the 2030 deadline, noted earlier.[55]

Satellites and Slavery in the Media

Journalists have a major role in increasing the awareness of global social issues, and modern slavery is no exception. Larger press organisations, such as Thomson Reuters and the Associated Press (AP), have also been enhancing their reporting with the use of satellite imagery to capture instances of slavery, exposing criminality and corruption.

The AP Pulitzer Prize-winning investigative report into the state of seafood supply chains within South East Asia included geospatial analysis to bring to light the working practices enslaved people were forced to endure.[56] The articles noted how labourers were trafficked to work in the Thai fishing industry and could be trapped on numerous boats in the Indian Ocean processing catches on board before being moved.[57] The investigation also found evidence of mass graves where enslaved workers had been buried, and captured the movement of fishing vessels across the ocean using satellite imagery.[58]

The investigation conducted by the AP raised the concept that you 'cannot hide from space'. Some forms of slavery, such as domestic servitude and carpet weaving, are not viable for investigation through the use of satellite imagery as the nature of the enslavement occurs indoors; this is the major limiting factor of remote sensing and demonstrates why a number of methodologies are required. Where industries can be viewed by remote sensing methods, which includes a significant number, the method can be beneficial, this includes the global fishing industry. As a result of the investigation, the Thai fishing industry came under intense scrutiny for its labour practices, and awareness of exploitation in these

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[55] United Nations General Assembly. "Transforming our World: The 2030 Agenda for Sustainable Development." Geneva, 2015.

[56] Details of the award-winning AP investigation are available via https://www.ap.org/explore/seafood-from-slaves/.

[57] Robin McDowell, Martha Mendoza, and Margie Mason. "AP tracks slave boats to Papua New Guinea." *AP*, accessed March 15, 2018, https://www.ap.org/explore/seafood-from-slaves/ap-tracks-slave-boats-to-papua-new-guinea.html; Margie Mason, and Martha Mendoza. "AP Investigation Prompts New Round of Slave Rescues." *AP*, accessed March 15, 2018, https://www.ap.org/explore/seafood-from-slaves/ap-investigation-prompts-new-round-of-slave-rescues.html.

[58] Robin McDowell, Margie Mason, and Martha Mendoza. "AP Investigation: Slaves May Have Caught the Fish You Bought." *AP*, accessed March 15, 2018, https://www.ap.org/explore/seafood-from-slaves/ap-investigation-slaves-may-have-caught-the-fish-you-bought.html; Annalee Newitz. "It took less than a minute of satellite time to catch these theives red-handed." *ARS Technica*, accessed May 4, 2018, https://arstechnica.com/tech-policy/2017/02/to-catch-a-thief-with-satellite-data/.

supply chains caused changes to law internationally.[59] It is clear that the global fishing industry is one with serious labour practice issues, and the exploitation evident in the workforce is being investigated in detail by a number of sectors including NGOs, academia and the media.[60] It is feasible that geospatial technology can be included in other studies of supply chain transparency in visible industries, contributing evidence to support reforms to worker's rights and industry practices. Industries believed to use exploitative labour practices include: quarries, mines, charcoal camps, cotton and agriculture among others. So far these industries have not been explored using remote sensing techniques.[61]

Satellites and Slavery as used by NGOs

A number of NGOs have begun to embrace satellite technology and imagery to demonstrate evidence of human rights violations. However, the use of geospatial imagery by the human rights NGO community has been criticised for the distance it can create from the complex realities on the ground.[62] Thus when analysing modern slavery from space, it is important to build a network of in situ contacts, crucially anti-slavery NGOs, so that evidence from satellite imagery can impact upon direct-action and influence the implementation of policy.

Amnesty International (AI) has been one of the most prolific at using these resources, creating a visual evidence base that supports survivor and witness testimony, enabling satellite imagery to be given as evidence in court; the most recent investigation with this aim assesses Myanmar Military action within Rakhine State.[63] A number of high-profile campaigns have capitalised on the vast amount of data available from geospatial technology and the organisation now employs its own team of analysts. Specific attention to slavery has been hidden within other human rights abuses but this does not mean that the work that AI has carried out using this technology is not beneficial. Their work has looked closely at the village of Baga, in Nigeria, after the atrocities committed by Boko Haram; assessing the scale of the destruction was vital to establish the story of the

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[59] Martha Mendoza. "Obama bans US imports of slave-produced goods." *AP*, accessed March 15, 2018, https://www.ap.org/explore/seafood-from-slaves/Obama-bans-US-imports-of-slave-produced-goods.html.

[60] McGoogan and Rashid. "Satellites reveal 'child slave camps' in UNESCO-protected park in Bangladesh."

[61] Bales. *Blood and Earth: Modern Slavery, Ecocide and the Secret to Saving the World*.

[62] Chris Perkins, and Martin Dodge. "Satellite imagery and the spectacle of secret spaces." *Geoforum* 40, no. 4 (2009):546-560.

[63] Amnesty International. "'We Will Destroy Everything': Military Responsibility for Crimes against Humanity in Rakhine State, Myanmar." London, 2018.

hundreds of women and girls who were kidnapped and enslaved by their captors.[64] Additionally, there have been extensive investigations by AI into North Korea's well-documented human rights abuses in labour camps and detention centres.[65] AI used satellite imagery to assess the size of the camps and identify features that indicate whether there are increased activities occurring in these locations, noting that camps were often in working order and expanding activities.[66]

The utilisation of geospatial technology in these cases has proved invaluable for raising awareness of NGO campaigns, but there are only limited technical analyses, often relying on the identification of features and comparison of images before and after an event. This information is still beneficial for an organisations' purposes, but utilising more technical details could help to provide new data that may have previously been overlooked, such as producing more detailed temporal analyses which may identify features in the lead up to a human rights abuse in order to predict when an abuse may be likely to occur in the future. In addition, combining witness testimony, imagery from the ground, satellite imagery and legal frameworks can add value to an investigation. It is important to look at these data holistically; this will be vital when applying satellite data to a complex human rights issue such as modern slavery. Work by Human Rights Watch, a non-profit organisation which investigates human rights abuses, is being revolutionised by new partnerships with emerging EO companies.[67] Commercial satellite providers, such as Planet, are moving from larger scale singular and expensive satellites to the launch and operation of multiple small satellites. These constellations of satellites collect a vast amount of data for global coverage at a reduced cost compared to other commercial operators, and can be flexible in their applications.[68] Recognising the need for data in the human rights sector, Planet has the intention of creating a new kind of global observatory whereby philanthropists provide the

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[64] "Nigeria: Satellite images show horrific scale of Boko Haram attack on Baga." Amnesty International, accessed March 13, 2018, https://www.amnesty.org/en/latest/news/2015/01/nigeria-satellite-images-show-horrific-scale-boko-haram-attack-baga/; Christoph Koettl. "The story behind the Nigeria satellite images." Amnesty International, accessed March 13, 2018, https://www.amnesty.org/en/latest/news/2015/01/the-story-behind-the-nigeria-satellite-images/.

[65] Amnesty International. "New Satellite Images Show Blurring of Political Prison Camp and Villages in North Korea." London, 2013; ---. "North Korea: New Satellite Images Show Continued Investment in the Infrastructure of Repression." London, 2013.

[66] "North Korea prison camps very much in working order." Amnesty International, accessed March 13, 2018, https://www.amnesty.org/en/latest/news/2016/11/north-korea-prison-camps-very-much-in-working-order/.

[67] "New Satellite Imagery Partnership." Human Rights Watch, accessed March 13, 2018, https://www.hrw.org/news/2017/11/30/new-satellite-imagery-partnership.

[68] Adrienne Harebottle. "Earth Observation to Capture the Mainstream Market." *Via Satellite*, accessed March 15, 2018, http://interactive.satellitetoday.com/via/may-june-2017/earth-observation-to-capture-the-mainstream-market/; Andrew Zolli. "Planet announces new, flexible emergency and disaster management." *Planet Labs*, accessed March 15, 2018, http://www.planet.com/pulse/planet-emergency-and-disaster-management-solution/.

funds, Planet and other companies provide the data and scientists and researchers come together to tackle modern slavery in a collaborative manner.[69] It is often the cost of the equipment, data, and expertise required to analyse imagery that can be prohibitive to the humanitarian sector; this is increasingly being considered by EO companies, who often have an emphasis on providing free data for humanitarian purposes.[70] Other organisations, such as DigitalGlobe, use the power of people to sift through vast amounts of information to help with specific issues (known as crowdsourcing). For the frequently unsafe and unmapped areas where humanitarian organisations work, remote sensing offers cross-national, time series data.[71]

Crowdsourcing

Crowdsourcing the analysis of satellite imagery has three key benefits in these circumstances. First, the datasets are 'Big Data', characterised by their volume, variety, and rapid rate of capture, which the remote sensing community is increasingly unequipped to manage alone.[72] Remote sensing data is varied and can be multi-source, multi-temporal, and multi-resolution. Second, satellite imagery analysis needs validation, because poor data comes with economic and ethical costs. Estimates of the prevalence and impact of modern slavery inform policy and, when derived from satellite data, mis-estimations could impact the resources made available to tackle slavery on the ground; data accuracy is important so as not to further endanger vulnerable people.[73] Crowdsourced data can be validated in a variety of ways, according to how the data will be used.[74] Third, and finally, human analysts are more creative and flexible in their assessment of satellite images than

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[69] Andrew Zolli. "Trust Conference Day 2 Keynote – Andrew Zolli." *Thomson Reuters Foundation*, accessed December 6, 2018, http://www.trustconference.com/videos/i/?id=d966ddc7-3909-4a02-9d16-0743b0946a79&confYear=2018.

[70] Susan R. Wolfinbarger. "Remote Sensing as a Tool for Human Rights Fact-Finding," in *The Transformation of Human Rights Fact-Finding* ed. Philip Alston and Sarah Knuckney. Oxford: Oxford University Press, 2016:463-478.

[71] Patrick Meier. *Digital Humanitarians*. Boca Raton, USA: CRC Press, 2015.

[72] Mingmin Chi *et al*. "Big Data for Remote Sensing: Challenges and Opportunities." *Proceedings of the IEEE* 104, 11 (2016):2207-2219.

[73] G.M. Foody. "Citizen Science in support of remote sensing research." *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)* (2015):5387-5390; ———. "Valuing map validation: The need for rigorous land cover map accuracy assessment in economic valuations of ecosystem services." *Ecological Economics* 111 (2015): 13-28.

[74] Hansi Senaratne *et al*. "A review of volunteered geographic information quality assessment methods." *International Journal of Geographical Information Science* 31, no. 1 (2017):139-167; Andrea Wiggins, Greg Newman, Robert D. Stevenson and Kevin Crowston. "Mechanisms for Data Quality and Validation in Citizen Science." *IEEE Seventh International Conference on e-Science Workshops* (2011):14-19.

computers, and online volunteers can increase the efficiency of data processing and analysis at less cost.[75]

The crowdsourcing of data for the humanitarian sector has been embraced both in the field, such as OpenStreetMap, CrisisMappers and Digital Humanitarians, and online, for instance, MicroMappers and Tomnod.[76] Industries known to employ practices of modern slavery have been analysed, as previously noted in the South Asian brick manufacturing industry.[77] The humanitarian crowdsourcing project Tomnod and the Global Fund to End Slavery, also employed these techniques to track instances of fishing activity on Lake Volta, Ghana; an area where there is a prevalent use of child labour.[78] The study employed the crowd to look for instances of buildings on the lake shore where vulnerable children may be being housed, boats on the lake, and fish cages in the water. Overall, the study recorded 244,006 instances of fishing paraphernalia and buildings across the lake and its banks.[79] Mapping Lake Volta was invaluable for the NGOs that contributed to the project, allowing resources to be targeted more effectively and helping support children subjected to enslavement.

Conclusion

Remote sensing for human rights analysis is developing at a rapid rate due to the frequent and widespread collection of satellite imagery. Efforts to apply remote sensing principles have commonly been used to provide resources to humanitarian crises, information regarding remote locations and conflict zones, as well as the management of disasters, as the examples here illustrate. The success of these studies have demonstrated that it is entirely feasible to apply these methods to the study of modern slavery; findings from the employment of remotely sensed data to end modern slavery are already being used by NGOs to inform interventions on the ground, and indeed it is hoped that these resources would lead to long-term

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[75] Mordechai Haklay, Suvodeep Mazumdar, and Jessica Wardlaw. “Citizen Science for Observing and Understanding the Earth.” In *Earth Observation Open Science and Innovation* ed. Pierre-Philippe Mathieu and Christoph Aubrecht. ISSI Scientific Report Series, vol 15. Cham, Switzerland: Springer, 2018:69-88.

[76] Steffen Fritz, Cidália Costa Fonte and Linda See. “The Role of Citizen Science in Earth Observation.” *Remote Sensing* 9, no. 4 (2017):357.

[77] Boyd *et al*. "Slavery from Space: Demonstrating the role for satellite remote sensing to inform evidence-based action related to UN SDG number 8."

[78] International Justice Mission. “Child Trafficking into Forced Labor on Lake Volta, Ghana: A Mixed-Methods Assessment.” Washington DC, 2016.

[79] Tomnod and World Freedom Fund. “Global Fund to End Slavery at Lake Volta, Ghana: Tomnod Project Report.” 2015:11-13.

monitoring and legislative change supporting survivor rights.[80] Focus on the use of remotely sensed data specifically for the study of modern slavery has begun, but there is much more that needs to be explored, including a range of data sources and industries.

At present remotely sensed data cannot account for the precise locations where modern slavery practices are occurring, but insights can be provided into industries which can then be used as a resource by those locally undertaking direct action. Remote sensing can never replace the data that is collected in situ by people regarding such an important social issue as modern slavery, however, satellite imagery can be used to support these methods and provide data on a scale that may not be feasible on the ground. Therefore, multiple methods of data collection are needed to successfully advance the fourth anti-slavery movement and eradicate slavery in line with the SDGs 2030 target and for humanity to benefit from the freedom dividend it would provide.[81] The use of satellite data could revolutionise the way we think about the hidden crime of modern slavery – as you cannot hide from space.

[80] Rights Lab. "Data Programme."

[81] Kevin Bales. *Disposable People: New Slavery in the Global Economy*. Berkeley, CA: University of California Press, 2012: Preface; Landman. "Out of the Shadows: Trans-disciplinary Research on Modern Slavery."

Figures

Figure 1: An example of brick kilns located in Punjab, India – note the distinctive red colour which contrasts with the fields surrounding the structures. 4-band PlanetScope Scene projected in true colour with 3m resolution. Imagery captured September 2018. Copyright 2018 Planet Labs.[82]

[82] Planet Labs. "Planet Application Program Interface: In Space for Life on Earth." *Planet*, accessed December 6, 2018, https://api.planet.com.

Figure 2: An example of a fish-processing camp in the Sundarbans Reserve Forest, Bangladesh. Captured by RapidEye-1 in December 2017, 5m resolution projected in true colour, copyright 2018 Planet Labs.[83] The inset DigitalGlobe Worldview image is from November 2014 shows details of the camp including boats and structures, downloaded from Google Earth Pro.

[83] Ibid.

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