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Review

Environmental Land Management and Assessment, in the Context of Resource and Climate-Related Conflict

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Abstract

This paper reviews the growing importance of satellite imagery to provide Normalized Difference Vegetative Index (NDVI) maps, relevant to environmental land management assessment, in the context of resource and climate-related conflict based upon our own humanitarian project-related support. Near real-time space-based monitoring benefits land assessment, human rights observers, and Non-Governmental Organizations (NGOs), in the presence of unstable regimes or socio-economic upheaval. Access to areas to validate claims or allegations with remote sensing tools and digital signal processing techniques is now important. Imagery-based assessment can quantify radiometrically calibrated NDVI, with temporal change indices, may evaluate displacement, to land clearances, and provide metrics on land use change. High-resolution satellite imagery can assess the extent of activities such as open cast mining, and dam construction in inaccessible regions, using semi-automatic orientated methods, generating indices at sub-metric levels derived from satellite data in: Red, Green, Blue, and NIR bands. We discuss the background of space-based applications, and the experimental methodology used. Results and discussion arising from a number of recent cases studies, with specific factors used to help with documentation and formulation of land management risk assessment in the context of climate change threats, e.g. wildfire, are considered. Satellite imagery combined with verified ground data sets of geospatial information and map making, allows external verification of ongoing and planned mining, or construction activities, which impact indigenous communities in such remote geographical regions, for example the controversial Ethiopian Gibe III dam. Seasonal and area change dynamics are observed and discussed.

Keywords
Normalized difference vegetative index; land assessment; climate change; conflict

1. Introduction

Land management as it is conventionally understood, is the process of managing land resource use, with its consequent development in both urban and rural settings. Since land resources are used for agriculture, forest and water resource management, land management may have a positive or negative impact on terrestrial ecosystems depending on how it is applied, or misapplied, particularly with activities such as mining, or the damming of rivers, which may degrade or greatly reduce productivity, disrupting natural equilibria. This is especially critical in difficult to visit areas, due to remoteness, conflict, or governmental prohibition. Environmentally sensitive areas in such circumstances require special monitoring and protection because of their landscape, wildlife, or historical value, and may be best ascertained from satellite imagery.

High resolution commercially available satellite imagery is one of several maturing technologies helping address such issues, to provide near real-time monitoring, and imagery verification across a wide range of land management-based activities including: remote surveillance of at risk indigenous groups, land use, and land cover. Such monitoring is highly relevant today, for example, looking at climate and demographic-related impact from the Crimea, to the Sudan, and the Great Lakes region. It is expected economic globalization and climate change-related pressures will increase both the frequency and severity of regional ethnic, resource motivated conflict, with pressures placed upon critical infrastructure [1]. From my research with civilian NGOs, UK Armed Forces, and the littoral capabilities of foreign navies, I have looked at such impacts on civilian conflict actors, in the context of environmental land management, and resources, documenting, and providing, baseline data to help mitigate similar future events [2]. Such data also supports initiatives from the coastal monitoring of illegal fishing with maritime drones, to anti-piracy operations in the littoral environment [3]. Satellite imagery provides the ability to monitor isolated regions, with embedded indigenous communities, and civilian actors at high risk of exploitation from both armed factions, and unethical economic exploitation.

2. Historical Conflict-related Satellite Land Assessment

High resolution satellite imagery for human rights was proposed just three decades ago, initially as a means of monitoring the Bosnian ethnic conflict [4], but it is only in the last decade that maturing satellite imaging technology of high resolution can now readily make this process available for practical humanitarian/environmental land management applications. Conflict, disaster, or operational land management strategic and tactical responses, depend heavily on the degree of available access, *permissive*, or *denied* to such areas. The degree of permissiveness afforded by 'host governments', or irregular actors operating within such crisis areas, may significantly influence the level of threat to unarmed civilian actors, the UN, Non-Governmental Organization (NGOs), and of course military forces. The importance of accurate space-based imagery increases as we move from a permissive environment, through an uncertain one in which irregular actors, otherwise armed or unarmed, create a climate of increasing insecurity and threat, to the highest hostility risk environment, often in areas of access denial, where lives may be under direct or imminent threat. For NGO workers, media users, and human rights workers, interested in land use change and demographic shift, and workers previously collaborated with, they do not require radiometric or atmospheric calibrated imagery; they simply want photographic evidence, and are driven by user, organizational and media requirements. Humanitarian workers and 'the press' are more concerned with image *detail* rather than normalized radiometrically calibrated images (Figure 1 and Figure 2).

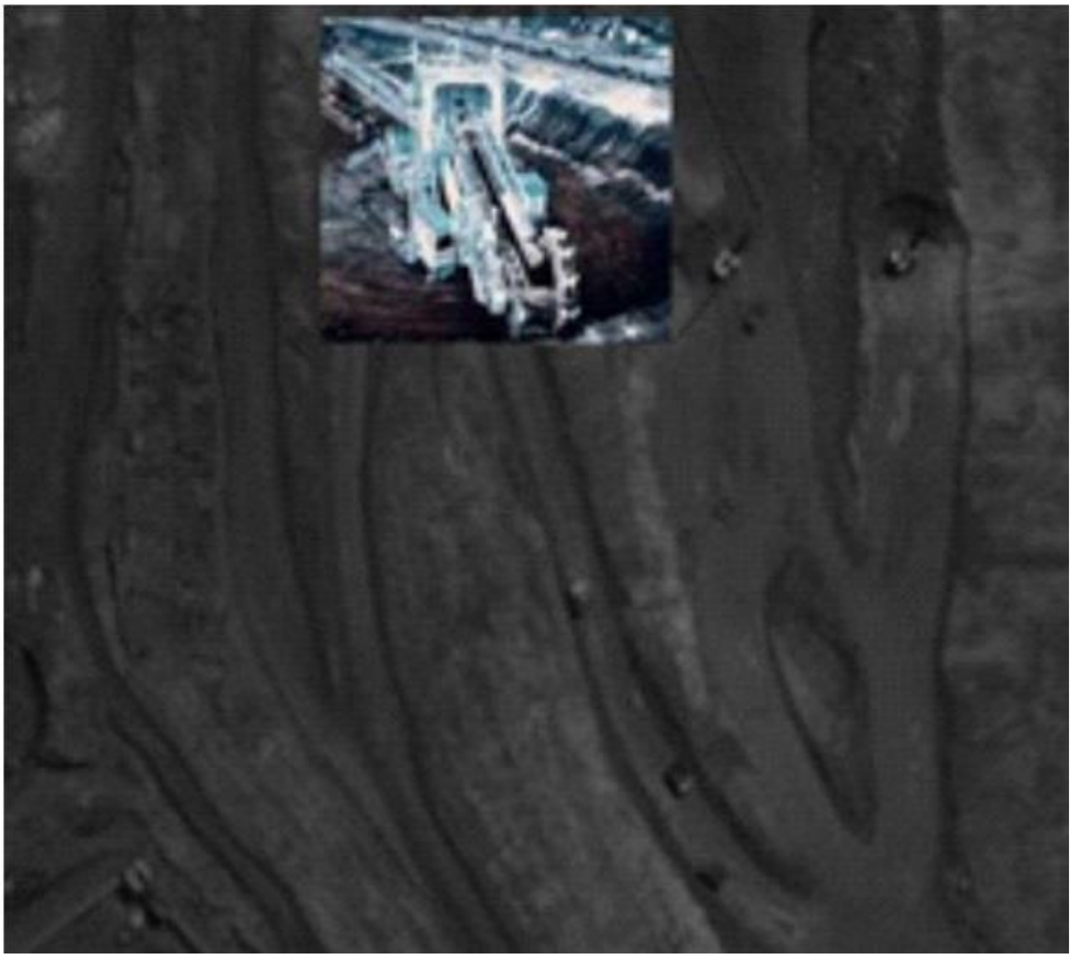

Figure 1 Individual vehicle identification is possible in West Papua Grasberg gold and copper mine, with extensive exploitative resource land management © GeoEye Foundation.

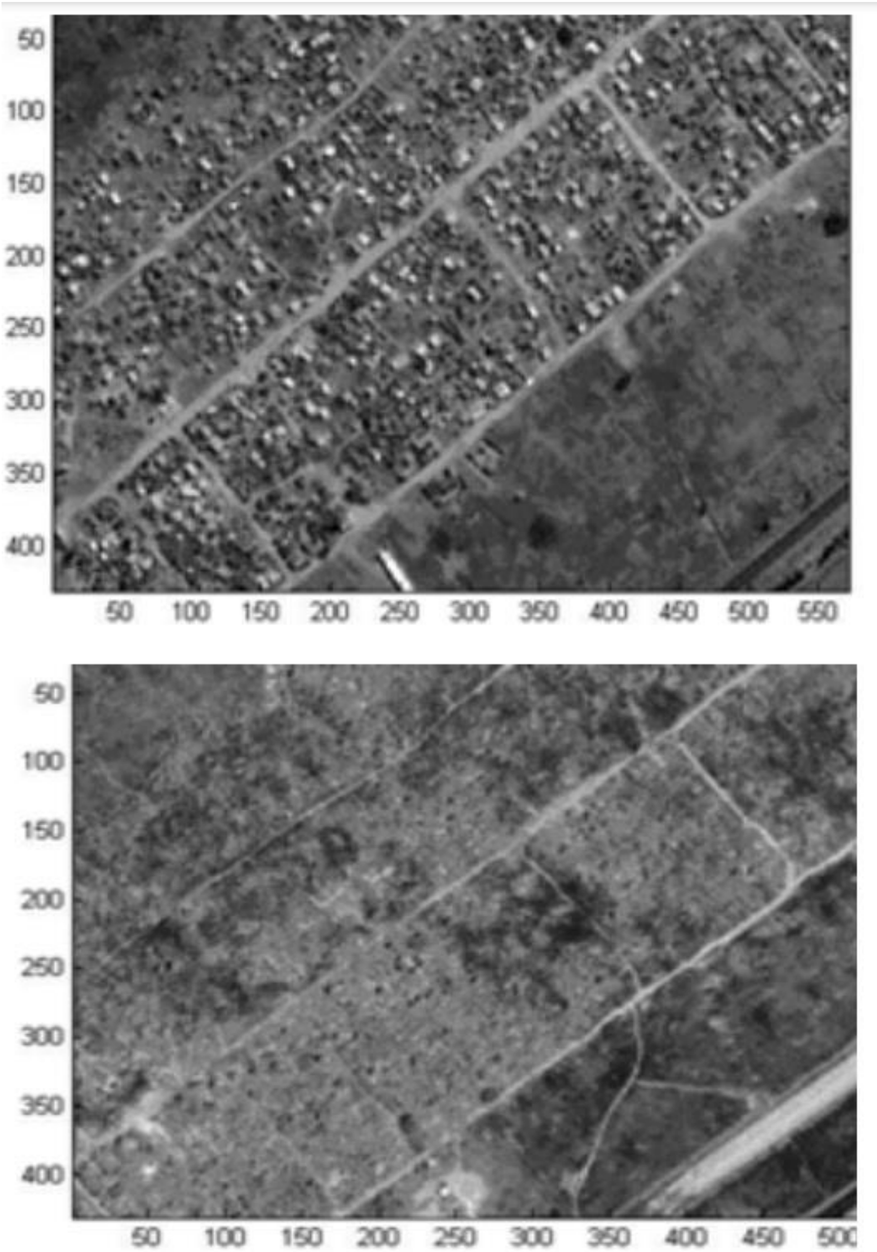

Figure 2 ’Before’ Panchromatic image 06-25-2000, ‘After’ 09-15-2006 Porta-Farm, Zimbabwe Land Clearance July 2005, © GeoEye Foundation.

Even the United Nations Institute for Training and Research (UNITAR https://www.unitar.org/maps/latest-maps), currently the largest humanitarian satellite imagery disaster provider, doesn’t provide Normalized Difference Vegetative Indices images, but almost exclusively annotated before/after image products. GeoEye, Digital Globe, and other companies provide metric and sub-metric space based imagery, Ikonos 2 and Quickbird 2 respectively, as well as the recent British company Earth-i, which routinely provides near real-time persistent space-based video for earth observation from satellites such as VividX2 (weighing just 100 kg). Commercial imaging is now available for Geographical Information System (GIS) related applications. Multispectral imaging typically provides colour and NIR data, to characterize both urban and rural areas in terms of land management. The current generation of commercial providers, complemented by declassified military imagery, is proving valuable for ‘*swords into ploughshares*’ applications using technology previously only found within the military domain. The global security landscape is changing rapidly, influenced by geopolitical and ideological shifts, with increasing pressures on refugee and ethnic communities often at society's margins; evidenced by recent humanitarian crises in countries such as Ukraine, and Afghanistan. However, the rapid technology expansion in this fourth industrial age, is producing a profound conflict shift regarding resource availability, with environmental and land management impacts on the global 'life-support systems', and economy, with potentially disastrous consequences for misplaced indigenous ethnic actors. Satellite imaging may thus be the *only* practicable means for monitoring and mitigating conflict, providing both quantitative and qualitative data to address the global strategic security challenges of our time, with the continued ability to monitor land use even in the absence of ground-truthing.

Market globalization and climate change-related factors are increasingly straining the fragile relationship and balance between high-tech resource extraction, with simple agrarian ethnic communities'. The greatest impact is on those nearest the bottom of the agrarian socio-economic scale. Land management impact by transnational companies' operations should be closely monitored, especially regarding those upon local indigenous communities.

High resolution satellite imagery has been associated with military operations and surveillance, since the Cold War. Historically, sensitive imagery was hard to disseminate due to its security classification, but ex-Soviet commercial provision of high resolution military imagery (degraded to 2m resolution), and the 1994 Clinton Administration Presidential Decision Directive, enabled several companies to access and resell high resolution imagery from American and Soviet Cold War satellites (the US Corona and Russian Federation KVR series respectively). A vital challenge for conflict abuse allegations on civilian actors is rapid response to reports (perishable information), often without precise location, and gathered under difficult conditions. Lack of information on affected area size, distribution, land impact (burning of crops, shelling of fields and communities), and numbers affected, an effective timely and measured response by the international community to the scale of a disaster, often with a significant land management component.

Geo-political situations are often further complicated by many governments' unwilling to allow Non-Governmental Organizations, and others, access to verify conditions or provide humanitarian relief on the ground, especially whilst conducting military operations. From a monitoring perspective, prevention is clearly more preferable and less costly than a cure. Using existing high resolution satellite imagery archives to supplement other verifiable data, e.g. eye-witness reports, helicopter, and increasingly UAV flights can provide vital tools to assess local land use, dwelling or population changes in a specific region, and generate urgently needed detailed maps for key resource access and management: water, shelter, food etc. Ground NGO work is certainly *assisted* by detailed satellite imagery. It is also a relatively affordable route to follow, as funding for satellite-based surveillance operations is generally much less than that required to support troops, or to undertake large-scale post conflict infrastructure rebuilding projects.

Aircraft or UAVs can take post disaster conflict images, but data collection is expensive, and time consuming, and clearly reliant on government permission. Conflict zone flights, such as those over Sudan and Yemen, or Ukraine, place manned flight staff in unnecessary high risk, especially if local forces don't want operations seen, potentially by a hostile global press. Sometimes satellite imagery is the ***only*** recourse for land observation as NGOs are effectively 'barred' from areas, even on the context of their own safety. Conflicts like Darfur in the Sudan, were, and to some extent still remain, high risk areas for ground personnel. It has been known for both UN and NGO vehicles to be hijacked, or aid convoys to be attacked, and vehicles hijacked. High resolution satellite imagery can corroborate reports gathered by field workers from our remote cases studies on indigenous land use in on global trouble spots. Eye-witness reports may be checked where available against satellite imagery for known latitude/longitude and corroborated against known GPS data. Typical satellite image characteristics may be noted for the following: village and structural removal, burn scars in fields and within urban areas, detection of both relocated and 'cleared' villages, the establishment of military camps and their expansion, as well as agricultural abandonment. In terms of refugees, we require the location and estimated numbers of those relocated into camps, often across international borders. Villages and structures are often removed by methods such as bulldozing, and new military compounds added, sometimes built by pressed local civilians, and foreign companies, colluding with oppressive regimes in the process. However, the cause of removal and land abandonment may not always be easily attributed to conflict; however systematic burning is compelling hostile evidence when combined with verbal ground eye-witness reports. Key features of 'before and after' imagery allow changes, e.g. burnt villages, abandoned fields, to be identified. However, there aren't always high resolution 'before' images, and acquisition may also be difficult if conditions are dark or cloudy (as is often the case with skies over Indonesian waters for detection of illegal fishing), but comparison of new with old imagery, in many reported areas, can be tested.

3. Satellite-based Methodology

Our 'standard' methodology firstly requires imagery acquisition, which may require satellite re-visit if weather conditions are inadequate. ArcGIS 10.2 was generally used with large GeoTIFF files (approximately 1.88 GB size). Overlap regions were extracted in multiple bands, often creating maps of features, e.g. a map of removed building by digitizing polygons. Geometric rectification is generally unnecessary as image data processed, geometrically rectified imagery, was usually provided by the supplier. The methodology, Figure 3, takes Digital Number (DN) sensor values, using a suitable radiometric calibration relevant to the satellite sensor in question converting DN values to at sensor spectral radiance, and then converts this spectral radiance to at sensor apparent reflectance [5]. The correction, followed for example in reference [5], subsequently removes atmospheric effects due to absorption and scattering with the Second Simulation of a Satellite Signal in the Solar Spectrum-Vector (6SV) method [6], yielding reflectance of pixels at earth surface. 6SV code enables accurate satellite observation simulation, accounting for elevated targets, anisotropy and gas absorption, based on a method of successive orders of scatterings approximations [7].

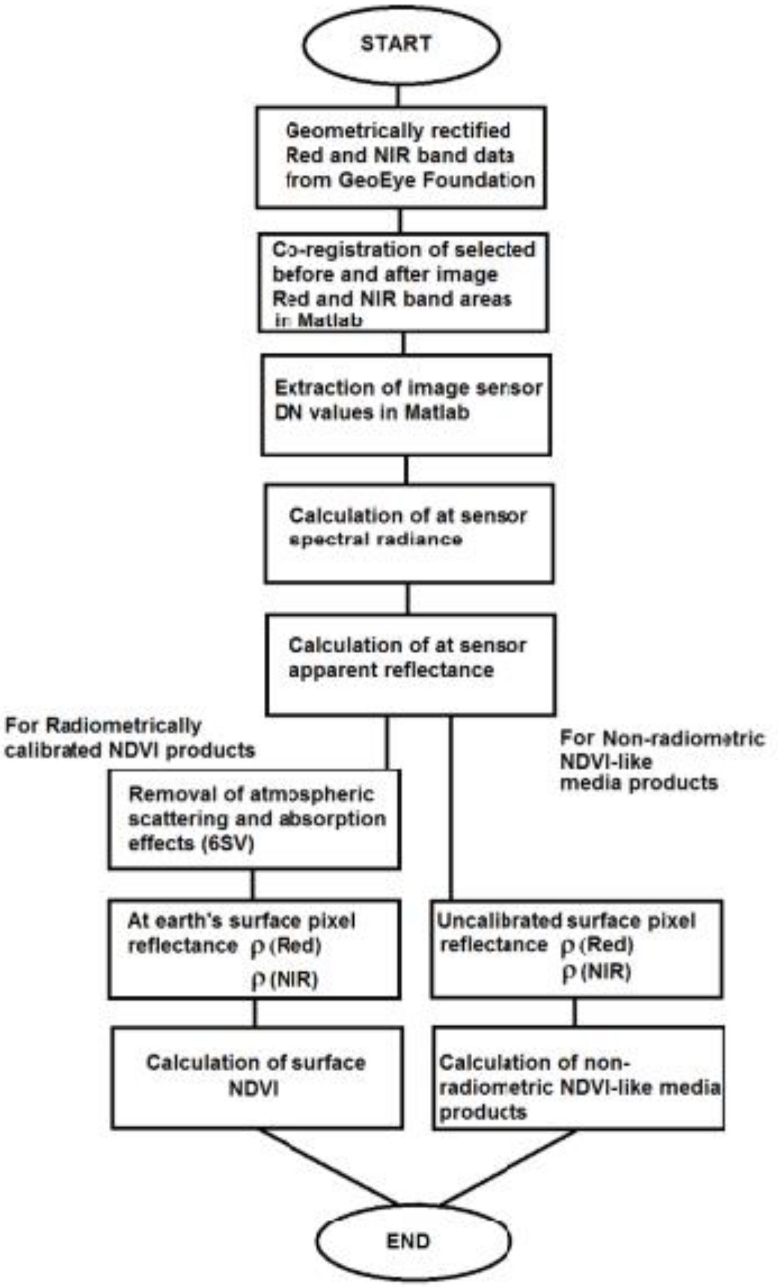

Figure 3 Typical Satellite-based Methodology Workflow Diagram.

3.1 Land Use and Land Cover Change Detection and Analysis

Landsat TM is a multispectral satellite providing visible, and NIR imagery to monitor land cover and use, or manage change. IKONOS 2 is a multispectral satellite with 1m panchromatic resolution, and four 4 m bands (0.42-0.52, 0.52-0.60, 0.63-0.69 and NIR 0.76-0.90 microns). IKONOS panchromatic and 4 m band combinations provide images similar to Landsat TM products. Manual building structure identification is time consuming; it is more efficient to identify large-scale clearance with minimal human input, so a pre-detection non-radiometric MATLAB process was chosen to locate large change areas for human rights or media-related analysis similar to Landsat NDVI. Humanitarian NDVI-related output doesn't require a radiometric calibration based on Landsat methodology [8]. IKONOS calibrated NDVI isn't identical to Landsat, due to band differences, and with IKONOS there are less bands. Human rights observers in any case are not interested in radiometric products, so non-radiometric assessment is legitimate. However, as an assessment factor on displaced communities, it may be useful sometimes to apply, after geometric correction and co-registration, with calibration for at-aperture spectral radiance, and at surface reflectance to correctly calculate vegetation products. MATLAB allows wide-area assessment of cover quickly, co-registering before and after imagery in single or multiple bands, ortho-rectifying pixel by pixel on scenes. MATLAB elements may then undergo matrix manipulation. Simple analysis uses:

$$\text{IKONOS } NDVI = \frac{(\rho_{\mathrm{NIR}} - \rho_{\mathrm{RED}})}{(\rho_{\mathrm{NIR}} + \rho_{\mathrm{RED}})}$$

following closely established Landsat methodology, e.g. with Landsat 8–9 for available bands then:

$$NDVI = \frac{(\mathrm{Band}_5 - \mathrm{Band}_4)}{(\mathrm{Band}_5 + \mathrm{Band}_3)}$$

NDVI is usually applied to vegetative land cover, in some media-related work or normalized media-related temporal imagery CT:

$$CT = \frac{(\rho_{\mathrm{After}} - \rho_{\mathrm{Before}})}{(\rho_{\mathrm{After}} + \rho_{\mathrm{Before}})}$$

Here the ρ value is the satellite camera's DN with an output index between modular values 0 to 1. Media outlets don't want actual NDVI; military and human rights surveillance operations often use single band comparison.

3.1.1 Image Data Processing

In our work, where required, using IKONOS imagery from the GeoEye Foundation archive, which generally provided geometrically rectified output for chosen comparative dates, we followed closely a methodology developed previously for land clearance assessment in Zimbabwe [5, 9].

The necessary methodology, shown in Figure 3, takes the Digital Number (DN) values recorded by the satellite's imaging sensor, in the chosen satellite bands, and converts these DN values to at sensor spectral radiance [6]. The at sensor spectral radiance is then converted to the at sensor apparent reflectance. A further atmospheric correction permits calculation of actual at earth reflectance. The spectral radiance L_λ observed at the sensor aperture can be calculated from the digital number DN_λ values and using the band calibration coefficients $CalCoef_\lambda$ and the bandwidth $Bandwidth_\lambda$ values for the satellite bands with the product metadata, by the equation:

$$\mathrm{L}_\lambda = \frac{10^4 \times DN_\lambda}{CalCoef_\lambda \times Bandwidth_\lambda} \quad (1)$$

where at-aperture radiance is equivalent to the exoatmospheric radiance.

From this planetary reflectance ρ may be obtained, defined by the equation:

$$\rho = \frac{\pi L_\lambda d^2}{E_{sun_\lambda} \cos\theta_s} \quad (2)$$

where d is the day-dependent Earth-Sun distance in astronomical units, E_{sun_λ} is the mean solar exoatmospheric spectral irradiance at an Earth-Sun distance of 1 astronomical unit, and θ_s is the solar zenith angle.

However, this is an exoatmospheric correction and does not correct for atmospheric effects. So this correction may be followed by removal of atmospheric effects due to both scattering and absorption (otherwise known as the atmospheric correction), with the Second Simulation of a Satellite Signal in the Solar Spectrum- Vector (6SV) method [5-7], to provide the reflectance of pixels at the Earth's surface. The 6S Vector code enables accurate simulations of satellite observations, accounting for elevated targets, with use of anisotropic and lambertian surfaces, and the calculation of gaseous absorption. The vector code is based on the method of successive orders of scatterings approximations.

3.2 Sudan Case Study

Conflicts in Sudan, South Sudan, the Horn of African, and generally cross-border impact in the African Great Lakes have demonstrated some of the most violent ethnic conflicts of the twentieth century, impacting heavily on local civilian populations: men, women, and children. Multi-dimension dynamics in such regions are complex, often a mixture of political, economic, and humanitarian connections, with various key actors, resources, and their consequent interactions. Conflict visualization of temporal as well as spatial relationships to identify 'patterns of life', to provide an appropriate response, is critical, and draws heavily from changes in land use and management under stressed conditions. Use of satellite imagery to comprehend complex regional armed conflict, combining traditional methods with digital data provides new ways to record and analyze such conflict, and its consequences, and relevant to ALL conflicts, not just necessarily military ones, at varying activity levels.

It is possible, using land cover maps and detected features, to target and identified key areas NGOs should avoid, i.e. danger zones, and likely attack areas with satellite imagery. Having collaborated with charities such as HART, which supports health clinics and medical facilities for vulnerable rural poor in several countries: Uganda, Nigeria, East Timor, and Armenia, we accessed with permission, Amnesty International's satellite monitoring of vulnerable villages in Darfur, Sudan (www.eyesondarfur.org no longer accessible) to test this assertion.

Their web-site represented a bold new approach which at the time put the previous Sudanese president Bashar's government on notice that their actions were monitored from outside the country. Von Uexkull [10] conducted and detailed empirical long-term test on drought and conflict in Sub-Saharan Africa between 1989–2008. These results proved her hypothesis that there is a positive correlation between drought and conflict. De Juan [11] continued to develop this concept to analyse the causal links between environmental change and violent conflict. Narrowing his focus exclusively to Darfur, he provided qualitative data, drawing upon visual geographical patterns of normalized difference vegetation index. This correlates with annual rainfall in Sudan and provides satellite imagery of the density and health of vegetation. According to De Juan's 2015 data, areas most impacted by in-migration were characterized by violent clashes. Our data covering Donkey Dereis in Darfur, in 2004 had hundreds of huts, but by 2006, had been turned into a landscape of overrun with burn-scarred vegetation as depicted in Figure 4 [2], and again using Geo Eye data, applied to Zimbabwe land clearance was quantified by us and others in terms of NDVI, Figure 5 [9].

Most of our data occupies the range of NDVI = 0–0.5, areas of generally low NDVI, with high NDVI only in newly planted agricultural fields, after clearance (Figure 5).

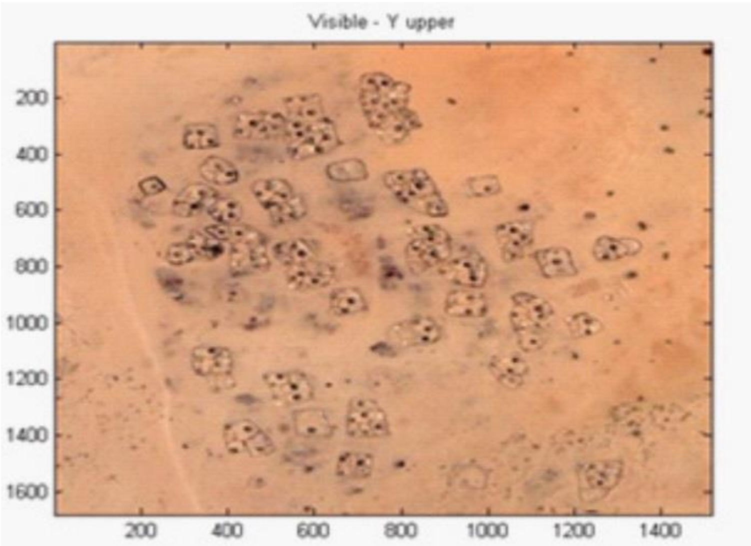

Figure 4 Individual Donkey Dereis, South Darfur, April 2006 Image Courtesy Amnesty International: 45 structures destroyed, 11 structures likely destroyed © Digital Globe.

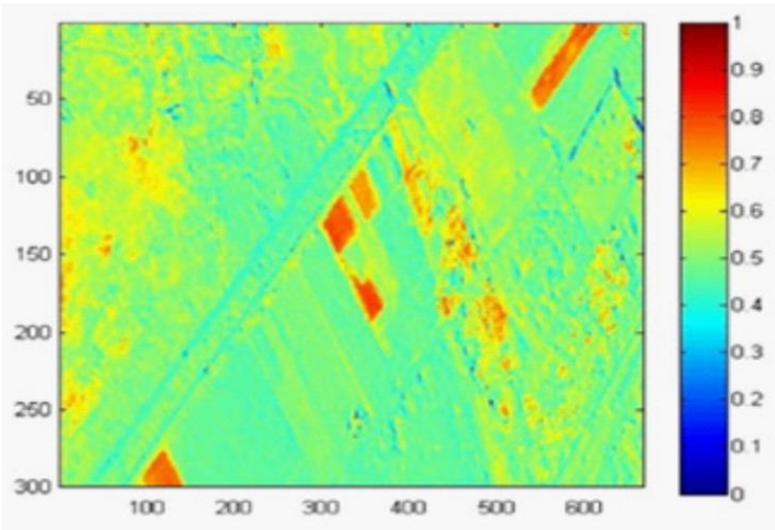

Figure 5 Radiometrically calibrated Porta Farm, Zimbabwe Normalized Vegetation Difference Index new agricultural developments, post clearance.

Another Zimbabwe conflict-related agricultural study identified roads beside minefields, from the reduction in vegetation at mine field perimeters, and the detection of mixed agricultural area regeneration from remotely sensed data [12]. Such approaches, used in these Zimbabwe Case Studies, *may* be applicable elsewhere, but do not replace surveys with ground penetrating radar, nor UAV thermal imagery. Early conflict-related agricultural environmental land management studies [13], showed that sudden reflectance changes could be clearly associated with crops, whilst re-vegetation was generally associated with abandoned agricultural land, and easily detectable from imagery separated by a minimum of 3 years duration [14, 15]. Witmer also examined the Bosnia-Herzegovia conflict (1992-1995) using Landsat imagery, the *de-facto* standard for land management studies at that time, using specific vegetation detection algorithms he developed [13]. Digital detection algorithms, combined with artificial Intelligence and machine-based learning, may in the future provide sufficient automation and digital filtering for space-based monitoring to provide near-real time data to international forces, NGOs, medical personnel, and human rights observers located remotely [16]. This is evidenced by recent work by Deininger, et.al, who used a 4-year (2019-2022) data period for 10 125 Ukrainian village councils to estimate expected winter crop yi8elds, classifying crop cover with machine-learning to compute NDVIs as a proxy for yields, estimating a 20% war-induced winter crop loss [17].

In the case of Darfur, Sudan, militia attacks combined with lower than normal rainfall in late 2008, further exacerbated existing refugee problems. There is little Spring rain annually (Jan-April), in spite of the green hue observed in regions of the White Nile, like Malakal, shown here in moderate resolution (2-4 m), provided by DMC International Imaging, Figure 6. After an initial short period of peace following Southern Sudan's independence from Sudan in 2011, 2013 saw the start of a bloody civil war, a conflict largely based upon Dinka and Nuer ethnic rivalries. After several broken peace agreements and ceasefires an estimated 400,000 were killed, with 4.5 million displaced [18]. Of those displaced, about 1.8 million were internally displaced, and the rest fled to neighboring countries, notably Uganda and Sudan [19]**.** Fighting in the agricultural heartland in the south of the country caused the number facing starvation to increase to 6 million [20], with famine in some areas [21]. The country's economy has been devastated, according to the IMF; in October 2017 real income halved since 2013, and inflation is now over 300% per annum. Today, there are significant indirect cross-border humanitarian consequences of conflict, besides the obvious direct consequences of conflict-related activities, with often great numbers due to food insecurity, disease, poor water or degraded health services, with high rates of sexual violence, evidenced by a 34% increase in cases perpetrated by State Actors (2018) compared with 2017 [22].

Figure 6 Malakal Sudan © Qinetiq 2009.

The Southern Sudan conflict had a huge humanitarian impact on civilian actors within its borders and across neighboring states, with estimates indicating that since 2013 7.1 million still remain in need of assistance and protection (ibid). By 2018 2 million Southern Sudanese, mostly less than 18 years of age, had taken refuge in the following neighboring countries: Uganda, Sudan, Ethiopia, DRC, and CAR, already stressed with ongoing conflicts of their own. Refugees and Internally Displaced People (IDP) camps are often located in borderlands areas, as we and others observed with Burma/Myanmar case studies [23]. Such population displacements creates challenging access issues, combined with a certain degree of hostility from 'host communities', which are arguably communities competing for limited available local resources, as evidenced recently in Cox's Bazar [24].

3.3 Environmental Land Mis-Management

Territory and resources have long been key motivations for war and activities which fall short of direct conflict by state, and non-state actors, perhaps more accurately termed *war/not war*, rather than war or peace. However, today in diverse and distributed locations around the globe, from West Papua, to the Great Lakes region, and the Sudan, the rich variety of natural resources available, themselves may drive and sustain conflicts, in an era of energy driven crises. Natural resources are strategically relevant, with national rivalries for coal, gas, rare-earth minerals, uranium, water, etc. *vs.* severe competition for access. There are several ways satellite imagery can provide 'metrics' on the scale of various resource trades, environmental damage, and environmental land impacts on life, and even water access.

We previously investigated West Papuan mineral exploitation [25], and potential Indian mining impact on isolated Dongriah Kondh tribes Figure 7 [26], to mitigate unlawful/environmentally damaging activities, which unaddressed may lead to insurgency as the only remaining available option to address real as well as perceived grievances, exacerbated by harsh geography and worsening climate, combined with diminishing glacial water resources, as in the West Papuan case (Figure 8).

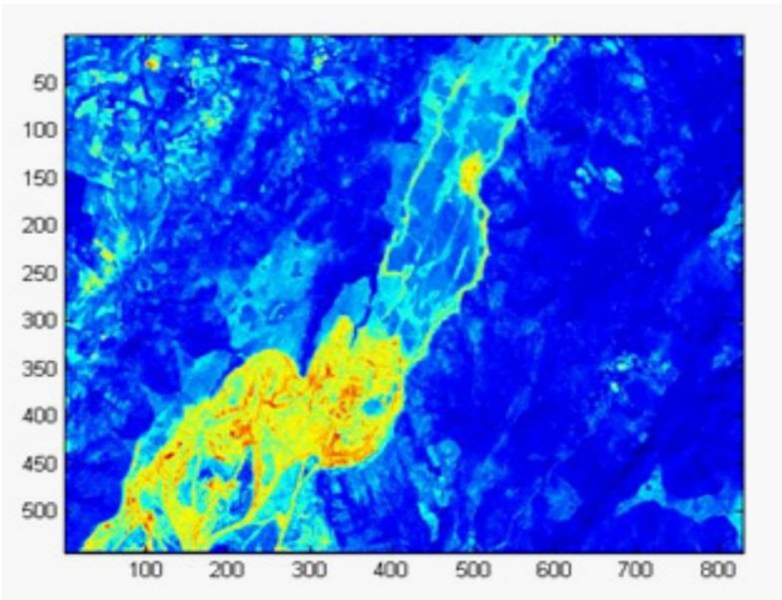

Figure 7 Malakal Panchpatmali Mine, Orissa, India, Change 2002-2009.

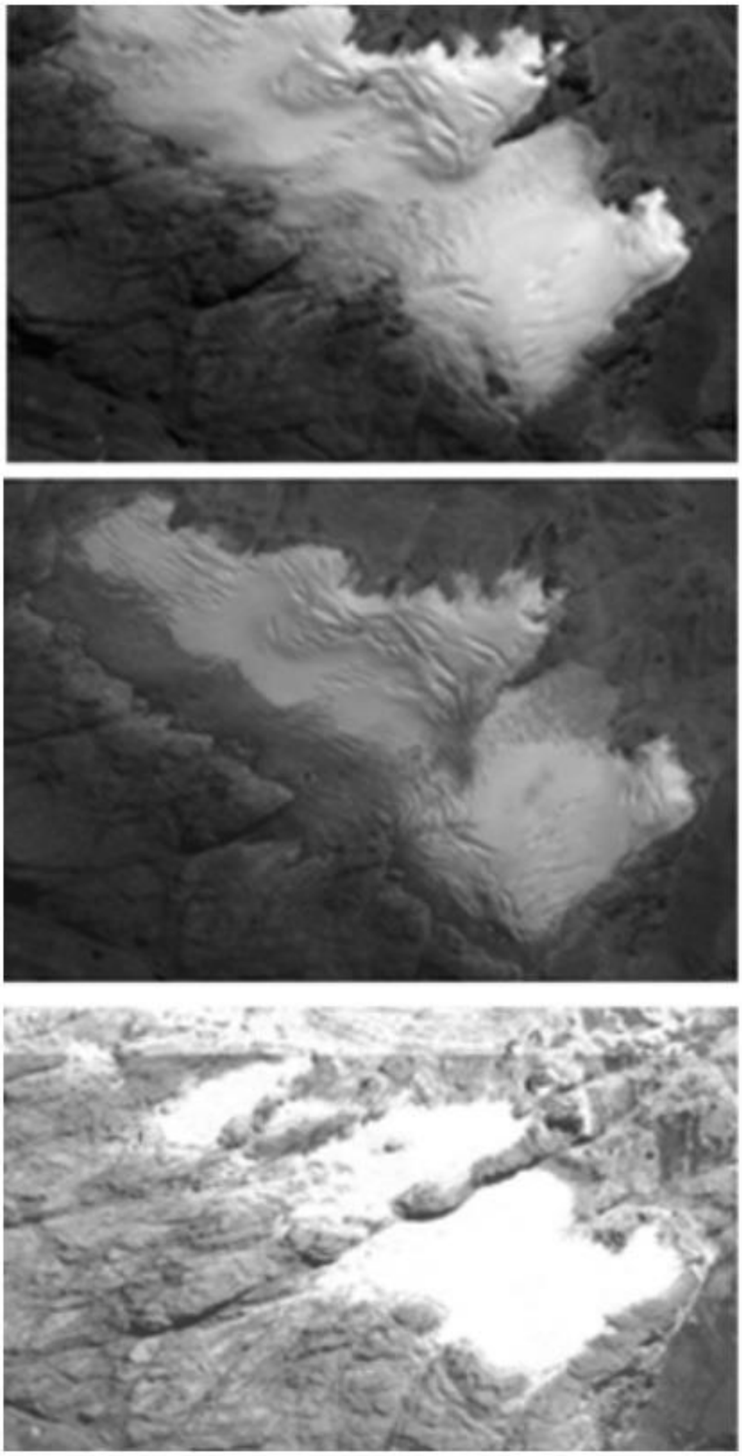

Figure 8 Northwall Firn, Puncak Jaya, top 2000, middle 2002, bottom 2016 © Pleiades.

Mining impact combined with water scarcity and ablation of the high alpine glaciers close to the Grasberg Copper and Gold Mine (Figure 9) has shown consistent multi-decadal retreat, and in recent years monitored by satellite imagery (Table 1). The mine [Figure 9] is seen with tropical glaciers right, sensitive markers of immediate climate change, over the period June 2000–2015 (Figure 8a June 2000 to Figure 8b June 2015 bottom). The mine complex stands at 12624700 m^2 with a bored-out central circular mining core, of 1850400 m^2.

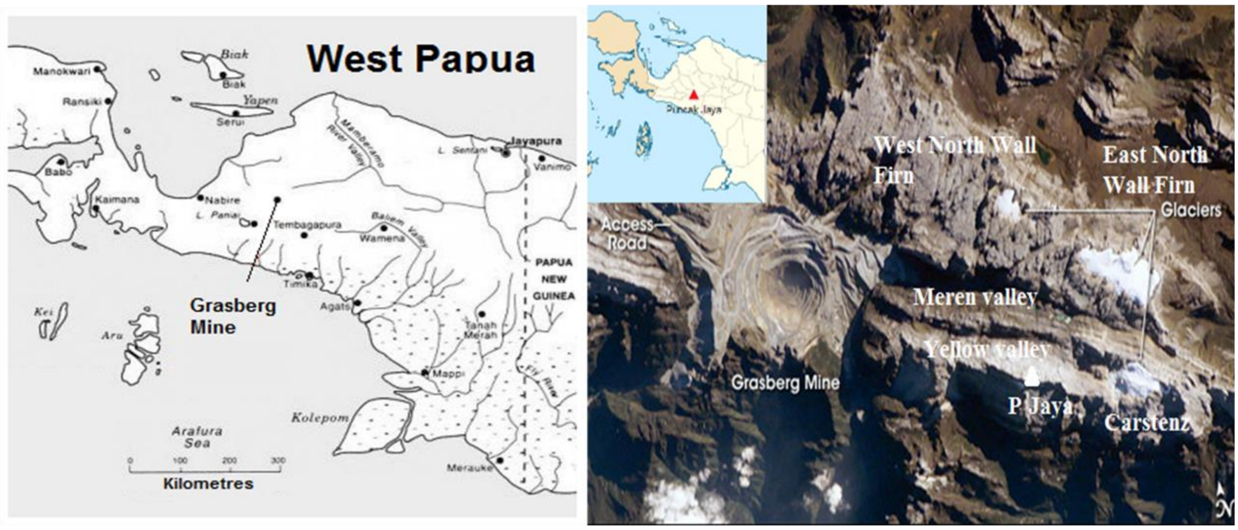

Figure 9 Topographical Map and Tembagapura mine.

Table 1 Greatest extent of decadal ice/snow cover derived from our acquired satellite imagery.

Year	Northwall Firn/m^2	Carstenz/m^2
2000	1470200	850000
2002	1537000	934000
2005	1195500	604100
2015	518000	186500

The East Northwall Firn is no longer a continuous ice field, but is composed of several smaller fragments, the biggest of which is 313,334 m^2, with other sections having now melted away. The decline of the ice fields has been documented since 1984 by Prentice [27].

Water issues are commonly encountered internal national issues, as well as crossing international boundaries, e.g. the damming of the Ethiopian Omo river by the Gibe III dam, which has impacted indigenous pastoralists, combined with the building of security camps (Figure 10). According to critics, the dam will potentially devastate the indigenous population [28]. The dam will stop the seasonal flood, which will impact the lower reaches of the Omo River and Lake Turkana, affecting the people who rely on these ecosystems for their livelihoods. According to Terri Hathaway, director of International Rivers' Africa programme, Gibe III is "*the most destructive dam under construction in Africa. The project would condemn "half a million of the region's most vulnerable people to hunger and conflict."*

Figure 10 Camps above, during Gibe III dam construction in Ethiopia prior to camp construction.

It is estimated over 200,000 people currently rely on the Omo River, below the dam, for largely subsistence flood recession agriculture, and many of these ethnic groups live in chronic hunger. The Gibe III dam may greatly worsen this situation. Indigenous people currently rely on recessional cultivation of food alongside its riverbanks, as well as nomadic pastoral livestock herding, for survival. The seasonality of rivers in this arid environment, with the associated decrease in water levels may be exacerbated or aided by the Gibe III dam [29]. The people living in the area are part of eight highly diverse people groups.

In our study of the Omo river [30], considering the 2002 river water body, and taking random samples of river water data points, it was observed NDVI values provided an average of -0.37 with a standard deviation of 0.09. Data samples broadly fell into two groups, one with more negative values for fast flowing deep sections, and less negative values for shallow slow parts of the river, which is reflected in lower values typically -0.2 for smaller tributaries. Considering the 2009 water body, and taking further random sets of sampled water data points NDVI provided an average of -0.6 with standard deviation of 5.2×10^{3}. In relation to rainfall this is not surprising as the highlands rainfall is quite different between March and September as found by Korecha [31] and entirely consistent with multispectral values of NDVI of -0.2 to about -0.7 which falls as another spectral quantity, the Modified Normalized Difference Water Index (MNDWI) increases from 0 to about 0.7, calibrated from TM/ETM+, and SPOT VGT data. Taking Ma's correlation [32], the water body in this case has a MNDWI of about 0.55. However, it must be stressed our data was derived from IKONOS imagery and not TM/ETM+ data.

Stephen Corry, current director of the indigenous rights organization Survival International has said, "*The Gibe III dam will be a disaster of cataclysmic proportions for the tribes of the Omo valley. Their land and livelihoods will be destroyed, yet few have any idea what lies ahead. The government has violated Ethiopia's constitution and international law in the procurement process. No respectable outside body should be funding this atrocious project*." There are similar concerns for indigenous Papuan tribes' resulting from the Rio Tinto operated Grasberg mine, the largest gold and third largest copper mine, and a key factor in Indonesia's economy. Although competition alone may not directly lead to conflict, it nonetheless raises tensions, with inaccessible geography lending itself to potential guerrilla warfare since the first violent incidences recorded in West Papua from 2002.

3.4 Natural Resources and Existential Societal Threats

Natural resources are not the only environmental conflict factor for societal destabilization. Societal infrastructure may arise from different categories: water, food, health services, emergency services, environmental protection, and electricity. Any large-scale disruption arising may be devastating to critical national infrastructure. Satellite imagery can help establish the risks to national infrastructure from natural, as well as military and terrorist hazards. The 2018 Berlin-based start-up LiveEO (Figure 11) demonstrated the first risk analysis of the complete US electric transmission grid using satellite-based vegetation. Analysis revealed vegetation conditions along some 574 thousand miles of overhead lines. LiveEO used 15,000 images to evaluate the risks, and detailed the analysis, which is found elsewhere [33]. Further analysis will inform land management processes to decrease wildfire and storm damage risk. The development of appropriate environmental land management strategies should include a clear methodology based where possible upon existing available sources of land relevant information, and include factors such as precipitation, humidity and wild fire risk. This process is discussed to some extent in section 4. There are many contemporary wildfire examples, but modern land management problems can easily be traced back to the first half of the 20^{th} century, and is a global problem. For example, farmers in Araucanía, Chile, regularly burned weeds and young forests before cultivating. In 1943, a combination of drought, illegal burning (during the southern hemisphere summer), and forest management problems turned a regular burning season into a wildfire disaster [34]**.** Environmental history researcher Gonzalez shows clearly that the history of the fires, as told through the region's newspaper *El Diario Austral*, is useful for understanding *how* the fires were embedded within larger themes in Chilean social, economic, and environmental history —and how the Araucanía fires were part of broader global trends in the history of land management and climate change, which continues to this date as a repeating theme.

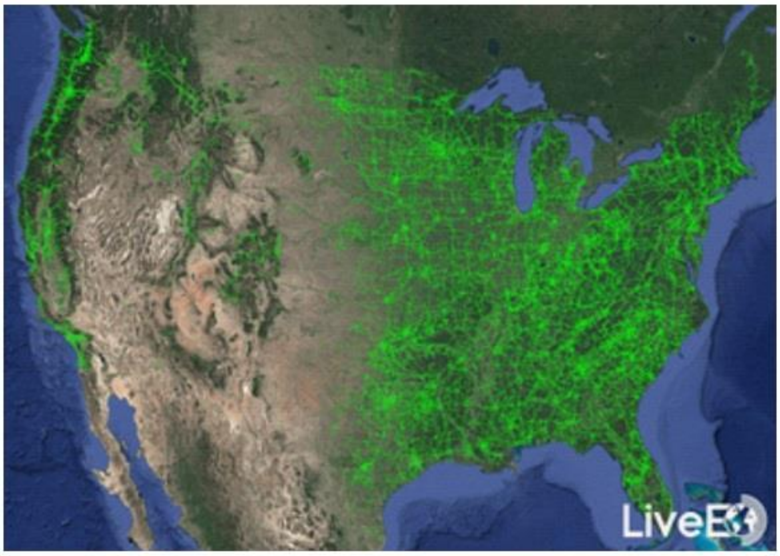

Figure 11 Satellite imagery mapping of the US Electrical Grid. Image Courtesy@ LiveEO.

Vegetation is one of the main challenges for utilities, causing up to 56% of externally triggered power interruptions, and so land management NDVI conducted from space using archived before, as well as recent imagery, may prove a better tool than attempting this with ground truthing alone. Applying such mapping to other critical national infrastructure elements will be a key activity for future UN operations, and others in the 21st Century, e.g. trying to restore power and other utilities when lost due to disasters, such as the recent United States' Hurricane Ian (2022).

The scale of LiveEO's project, combined with the detail of the analysis, represents a milestone in satellite data analytics for utility companies and proves that satellite data really can represent a viable alternative for vegetation management to current Lidar methods, or foot patrols. Such methodologies may be especially useful in Africa, e.g. in Southern Sudan, home to some of the oldest African teak plantations, but now beleaguered by an illicit hardwood trade now important in regions plagued by trans-national wars. For example, the Central Equatoria teak economy, where one of our partner organizations HART operates, the forest is difficult to police, and estimated to provide 50–70 M US dollars per annum. Illegal harvesting often takes place with permission of local and *defacto* authorities, in the same way as traders defer to *Al Shabaab* throughout Somalia for various permissions, rather than to official Governmental authorities. South Sudanese government figures suggest there is nearly 200,000 km^2 of forested land, covering 29% of the country's total area. Teak is not indigenous to Africa, as natural teak forest only occurs in 4 countries: India, Laos, Myanmar and Thailand, with logging heavily restricted in all of these except Myanmar (Burma), the leading supplier of teak worldwide. Indonesia is a key producer, from its plantation stock. However, seedlings were planted in the colonial era across the entire African continent, from Nigeria, to Southern Sudan. According to forestry expert Abdalla Gafaar, the first plantation in South Sudan may be dated to 1919, at Kagelu, Central Equatoria. Planting activity intensified in the 1940s, across the entire Equatorias and Bahr el Ghazal. In 2004, 13 teak plantations were mapped by satellite, and in 2007, a further 5 plantations, covering some 76.8 km^2, all found with satellite technology. Most of the mature trees standing today are between 35-50 years of age. Satellite imagery can provide independent evaluation of the overall state of the logging industry, as observed with Borneo forestry imagery, and is applicable to general global hardwood monitoring [35].

4. Towards a Practical Environmental Land Management Risk Assessment Methodology

Environmental land management is an important topic in the context of climate change, which although a global issue, manifests its impacts in terms of events, weighted by local physical, social and economic factors specific to any given area. Natural hazards such as floods *may* be enhanced by poor land management strategies or military crises. There is need to predict, prevent and build resilience against such risks and remain adaptable for the future. Good environmental land management may be a significant mitigating factor against weather-related impacts, and helps minimize existing vulnerabilities to natural periodic hazards.

A suitable environmental land management risk assessment methodology should support government commitments in national resilience, identifying the beneficial impact of any land management mitigation measures in terms of better land use, or reduced monitoring costs, and time. Details about the study location is important, using ground truth assessment and satellite imagery to establish the extent of a particular monitored location in physical terms of its size and distribution. Where available a suitable environmental planning portal, e.g. in the UK GEOViewer Pro [36], may help provide land quality assessment existing for the site in question, or accessible web pages about the location may be used. The environmental setting is critical, relying upon factors, such as its underlying geology e.g. the bedrock geology, for which much information in the UK is readily available from the British Geology Society (BGS) mapping, https://www.bgs.ac.uk/geological-data/map-viewers/.

There should be a brief review of potential environmental land management risks, with consideration of potential flood and fire risk, e.g. the UK has experienced an increase over the past 50 years in its contribution to winter rainfall from heavy precipitation events. Heavy precipitation events are now projected to increase across the UK in summer and winter, leading to increase in fluvial and surface water flooding. Flooding is identified as one of the highest priority risks for the UK with the UK government making substantial investments in increasing resilience in this area, and includes investment in natural land management measures, and sustainable urban drainage, to mitigate increases in long term flood risk. Flood maps can provide information on surface and river water, groundwater and coastal flooding, to complement hazard risk and strategic maps with information on areas prone to river and sea flooding. In the UK catchment flood management plans and risk map and datasheets are readily available.

Any review should include at least a consideration of the following E to H criteria:

Ecology: helps establish any notable ecology features, e.g. sites of Special Scientific Interest, and the special protection areas within, or close to, the study location, as well as known protected species.

Forestry- considerations help evaluate whether there are any woodlands either within or close to the specified location. Here DEFRA's Magic map, https://magic.defra.gov.uk/magicmap.aspx, holds information related to habitats and species layers, e.g. the location of remote high-altitude ancient English temperate forest.

Geological hazards include recorded landslides, swell-shrink potential, groundwater flooding, compressibility potential, and local rock solubility etc. Geological hazards *may* be exacerbated by climate change, especially due to increased probability and intensity of extreme events, including very dry and wet periods as discussed by Mabey [1].

Hydrogeology and *Hydrology*, allied with geological hazards, help provide answers to questions concerning the presence of major aquifers, or water abstraction levels. Again in the UK there is often ready access to DEFRA's Magic map, in order to review groundwater protection zones, aquifer designations, groundwater, with national vulnerability layers, available since August 2017. Hydrology depends upon the topography of the study location, and should include a full consideration of rainfall, for inclusion on flood risk assessment maps.

4.1 Water Resources

In 2017 it was estimated that by 2050 many water catchments across the UK will have to manage significant water deficits and manage competing demands for water for public supply, industry, agriculture and environment. Climate change combined with population growth and redistribution, will impact environmental land management as they increase existing pressure on water availability. Climate change will likely alter the water cycle as the amount and distribution of rainfall changes, although the extent to which this will take place is uncertain. Short duration droughts however, may become more frequent in spite of the increased resilience of public water supply, and if so will require greater winter storage across the UK. Although the availability of water for UK abstraction does varies annually, the balance between available resource and abstraction demands during stressed summer months will significantly impact farming, especially high intensity water demands of dairy farming. Water resource availability in the East, and South East of England, is difficult when compared to otherwise drier, but better prepared countries, like Spain or Italy, and is displayed using water exploitation indices such as the European Environmental agency water exploitation index, providing drought risk under various future scenarios, [37].

4.2 Wildfire Risk

In terms of land management of wildfires, regarded as a high priority risk for the UK. Wildfires are usually started by human activity, but hot, dry, and windy weather conditions increase the incidence of wildfires and their spread. It is important to build resilience of terrestrial ecosystems to flood, drought and fire, and manage the response to such wildfires. Existing wildfire data indicates the UK fire season usually occurs March–May, and July–September, and that in years of significant drought: 1995, 2003, 2006, and 2022, the number of wildfires increased significantly. Risk is particularly high in heath and moorland, and forests with grass, gorse and heather. Manchester University suggests a 1°C increase in summer average temperature will lead to a 17–28% increase in outdoor fires in England. In 2012 the UK started to use the Mc Arthur Forest fire Danger Index (FFDI) [38], which looks at the conditions which impact wildfire frequency. Analysis indicates the FFDI will likely rise across the entire UK by the 2080s, with greatest increase, over 40%, in the South East of England. Land management practice must consider such indices and take appropriate measures to deal with flammable organic material before they represent a significant wildfire hazard. Any land management risk methodology must include climate risk with relevant projection for planning to adapt to a changing climate. In the UK such a methodology was designed by the Met Office, based upon temperature, precipitation, and humidity, to evaluate mean daily maximum/minimum summer and winter temperature, mean summer and winter precipitation, precipitation changes, humidity, cloud cover, etc.

5. Conclusions

'Before' and 'after' satellite imagery comparison may corroborate reports of altered land use, such as building removal, or agricultural changes. Spectral and temporal comparisons of radiometrically calibrated NDVI-products, generated from known corrections, can quantify data by providing remote visualization of land use and land cover related to a wide range of humanitarian crises, in some cases exacerbated by man-made conflict, or natural climate causes, e.g. wildfires. Use of automation, and a range of digital filters, in conjunction with space-based wide-scale monitoring will provide future benefit to remotely located international human rights observers to provide perishable information over a rapid time-scale, identifying large-scale clearance with minimal human input with pre-detection non-radiometric MATLAB processing locating large building change areas quickly, without calibration. Panchromatic data for successive dates should be co-registered before clearance or before and after an event, e.g. for building removal identification.

The postscript of what happens to those displaced in such land clearances, is not generally good. For example, for those dispersed at Porta Farm, ironically a settlement developed over a fifteen year period from previous displaced settlements, unsurprisingly generated further settlements, such as Hopley Farm, near Harare, Zimbabwe. As another author put it "*The persistence of urban challenges in emerging communities makes it difficult to attain inclusive, resilient, sustainable, and safe communities?*" [39]. Such chronic ongoing situations have a clear detrimental impact on the socioeconomic, political, and environmental situation impacting settlement residents, and also is set at odds against prior residents, where conflicts arise between those that have, and more strictly those that have not yet had what they have, taken away. Communities are vulnerable to disease outbreaks such as endemic cholera, typhoid, malaria, and other transmissible diseases, such as the novel coronavirus, or potentially more dangerous viruses, such as Ebola. Any local impacts of natural disasters and climate change, such as flooding, or drought, impacts local harvests, exacerbates difficulties underlying such communities. Now, fifteen years later, at the same point Porta Farm was cleared, the current Hopley settlement is still developing, but life can be characterised by a general lack of basic service provision, displaced households, evictions, and intimidation. How residents can build lasting communities, relationships, and overall generational improvements in living standards, or wealth generation, with such multi-decadal long-term threats of forced dispersion and displacement hanging over them, without strong protection in law, whilst trying to go about their daily lives, is bleak and unclear.

In the presence of increasing population, resource scarcity, climate-change pressures, ethnic rivalries, and religious conflict, the importance of time-location stamped high resolution satellite imagery verification, will become more important to land and environment management, global risk assessment of conflict actors, and for the security of critical infrastructure.

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Competing Interests

The author declares that no competing interests exist.

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