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Abstract

Following more than 20 years of civil unrest, environmental information for Southern Somalia is scarce while there is clear evidence that the war economy fuelled by the conflict is rapidly depleting the country's natural resources and especially the woody biomass. Wood charcoal production is one of the most relevant businesses supporting war regimes such as the extreme Islamist group Al Shabaab, which has ruled in Southern Somalia from 2006 to 2012 and is still occupying large areas. In this study we first used Very High Resolution (VHR) satellite imagery of February 2013 for developing a semi-automatic mapping method of charcoal production sites as a proxy of tree loss over a 754 km^2 woody area along the Juba river in Southern Somalia. The accuracy of semi-automatic charcoal production site detection varied between 80 and 95% as compared to visual interpretation and reduced significantly the subjectivity and the required time. The analysis was then applied to previous years (2011-2012) for a 52.6 km^2 subset of the study area, and led to a tree loss estimation of 8.63%, corresponding to 15,434 trees over the 3 years period. The results are crucial for better understanding the dimension and impact of charcoal production in Southern Somalia and are a first step towards the development of a charcoal production monitoring system.

Keywords: charcoal, deforestation, Somalia, Al Shabaab, remote sensing, very high resolution

1. Introduction

Wood charcoal is the main cooking fuel across rural sub-Saharan Africa and to a large extent in urban centres. More than 90% of urban households in sub-Saharan Africa use charcoal as their main source of cooking energy (Zulu & Richardson, 2013), and the demand is likely to increase for several decades with growing urbanisation (Arnold et al., 2006). Charcoal production is an important source of income or coping strategy for subsistence farmers and pastoralists (Ghilardi et al., 2013) and the scarcity of alternative jobs makes the business attractive mainly for large portions of the young and unemployed male population (Kirkland, 2011).

In Somalia, charcoal is the major fuel for domestic cooking in urban areas including the capital Mogadishu and the country's charcoal need is met by domestic production. Before the civil war, industrial uses of charcoal were relatively minor and exports prohibited by law, while production areas were licenced by the former National Range Agency (Robinson, 1988). Since the beginning of the civil conflict in the early 1990s, charcoal production has been increasing dramatically and despite several export bans launched by regional governments, export to the Arabic Gulf countries has seen a rapid and steady increase (UNEP, 2005). Exact numbers on production, export and deforestation rates are generally scarce. An earlier study by FAO estimated that Somalia consumed an estimated 80,000 tonnes of charcoal in 1983, with Mogadishu accounting for over half of this with 42,000 tonnes recorded entering the city that year (Robinson, 1988). The main tree species exploited are Acacia bussei and Acacia senegal and annual deforestation rates of ca. 3% were found in semi-arid areas of North Eastern Somalia by using Very High Resolution (VHR) satellite imagery (Oduori et al., 2011). But in the Southern and Central parts of the country, where access has been extremely limited over the last 20 years and practically impossible from 2008 under the control of the Al Qaida linked Islamist group called Al Shabaab, no recent data can be found. In July 2011 the charcoal business in Southern Somalia was suddenly brought to the attention of the media by a report of the United Nations Monitoring Group for Somalia and Eritrea (SEMG) (UN, 2011). The document affirmed that: “charcoal is the single most important source of income for Al Shabaab” and estimated the tax entries from charcoal trade to 25 million USD for the year 2011. In February 2012 the UN Security Council passed resolution 2036 (UN, 2012a) which issued a ban on charcoal exported by Somalia. Again in July of the same year, the SEMG provided more detailed evidence of a sharp increase of illegal charcoal exports in 2011 to the United Arab Emirates (UAE) and to the Kingdom of Saudi Arabia (KSA), due mainly to higher demand in these countries and to the practise of humanitarian aid transport vessels to transport charcoal on their return from Somalia (UN, 2012b). Before 2011, charcoal export to the Gulf countries had already increased in 2000 following a ban on livestock exports from Somalia, which pushed pastoralists towards charcoal production to compensate the lost income (Holleman, 2003).

In August 2011 Al Shabaab was forced out of the capital Mogadishu by the Somali National Defence Forces (SNDF) with the support of the African Union Mission in Somalia (AMISOM), but the group continued to hold vast parts of South and Central Somalia, including the important port of Kismaayo, from where most of the international charcoal export was operated. In 2011 it was estimated that 80–90% of the illegal charcoal exports were leaving Somalia through the port of Kismaayo (Kirkland, 2011). When the international forces under AMISON control entered the port of Kismaayo in October 2012, they found the port surrounded by an impressive wall of piled up charcoal bags ready for shipment. Early estimates talked about 4 million bags, at a total value of approximately 40 million US Dollars (McConnell, 2012). Despite the very large media coverage of the finding and of the negotiations on its final use, no information was available on the source areas of the charcoal, nor on the extent and impact of the resulting forest degradation.

The need for clear evidence on the origin of the Kismaayo charcoal and in general for detailed information on charcoal driven deforestation reached a peak in late 2012, but continues to remain high, following information that the business continues at a similar intensity as before October 2012 (UN Security Council, 2013). This report also points out that smaller ports along the Somali coast such as Baraawe are becoming more important for charcoal export, leading to the assumption that with the north-eastwards retreat of Al Shabaab, charcoal production patterns similar to those found by Rembold et al. 2013 West of Jilib, can also be expected on the East of the Juba river.

The objective of the work presented here is first of all to establish a semi-automated method to accurately localize charcoal production sites on very high resolution imagery, and then to analyse the degree of forest degradation for hotspots within the production zones under Al Shabaab control. The study area is still centered around the town of Jilib in Southern Somalia but extends also to the East of the Juba river and is 10 times larger than the area covered by Rembold et al. (745 square kilometres as compared to 71).

Since most of the rural areas in Southern Somalia are still occupied by Al Shabaab militias, field surveys were and are impossible to undertake.

2. Methodology

2.1 Data and object based image analysis

WorldView-1 imagery for February 2013 (4 scenes of 19 February) was available for an area of nearly 1000 km^2 and has been provided by the US Department of State. From this area, agricultural land was excluded, to perform the analysis on natural vegetation only. This left a remaining study area of about 754 km^2. The WorldView-1 sensor produces panchromatic images with a resolution of 0.5 m and the potential of these images for charcoal production site detection had been tested in Rembold et al. (2013).

Out of the total area covered in 2013, multi-temporal images taken in 2011 and 2012 were available for a small subset of approximately 52 km^2 and all images have been acquired during the month of February of the respective year (Fig. 1). The 2011 image was a WV1 image too, while the 2012 image is a multispectral QuickBird image.

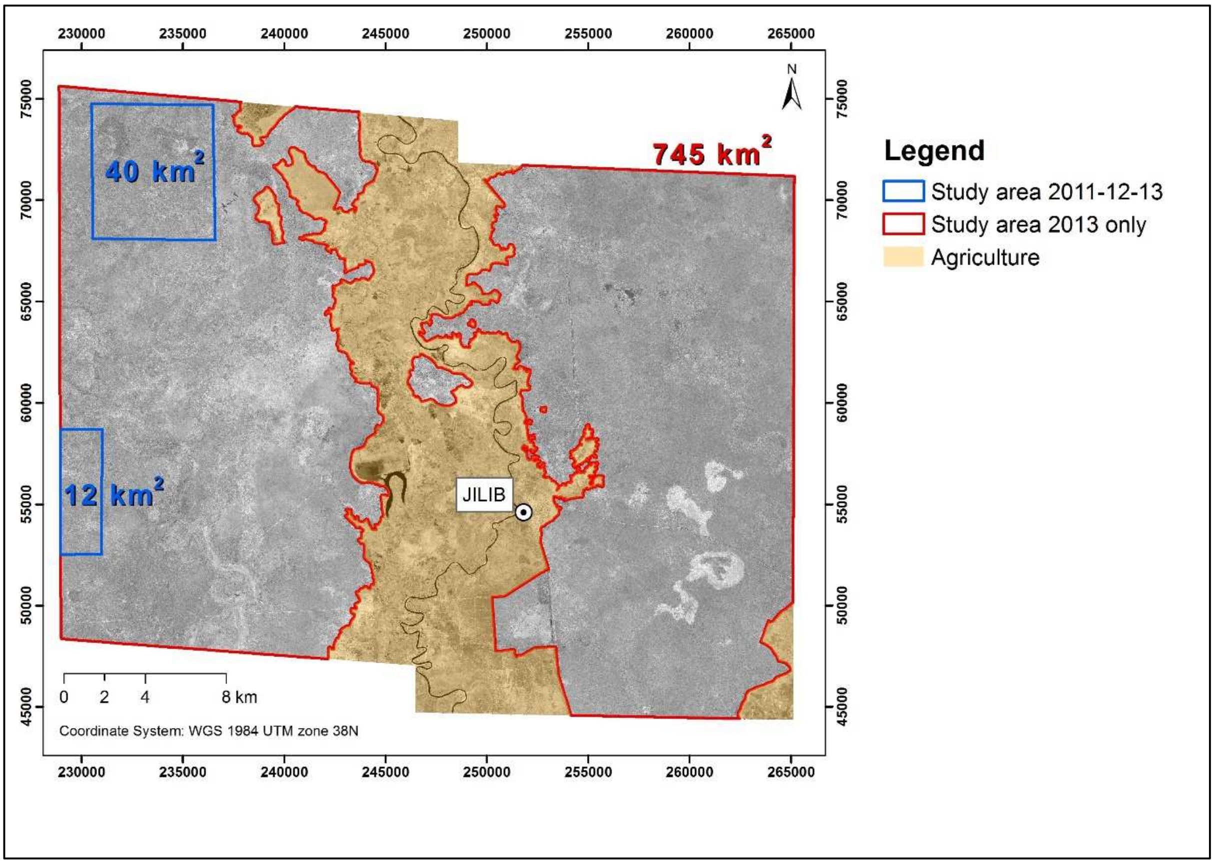

Fig. 1. Study area in Southern Somalia along the Juba River. *Image Copyright DigitalGlobe.*

As shown by Rembold et al. 2013 recent charcoal production sites are well visible on VHR imagery provided by sensors such as QuickBird (0.6m resolution) or WV (0.5m resolution), while individual tree crowns can hardly by distinguished in the coastal forests of Southern Somalia. But while the previous site detection was based on visual interpretation, the present study focusses on the development of an object-based image analysis (OBIA) approach for a rapid and non-subjective identification of charcoal production. In an OBIA, the idea is to translate the human visual perception into rules to identify image objects in semi-automatic ways, increasing the repeatability and production, while reducing time and costs (Hay & Castilla, 2006). The software eCognition (Baatz and Schaepe, 2000; eCognition, 2011) has been used to perform object-based image analysis, and the various segmentation options embedded have been explored. In eCognition the segmentation is based on three parameters: scale, a unit-less parameter used to control the heterogeneity of objects, with a lower scale parameter resulting in smaller objects; shape, a value that modifies the relationship between shape and colour criteria, and optimizes objects for spatial homogeneity when set to 1; and compactness, where higher parameter setting correspond to more compact image objects (eCognition, 2011). Segment optimization aims to minimize under- and over- segmentation in order to increase the efficiency and accuracy of classification. Even if charcoal production sites do not present high spectral and size variability, a single optimal scale parameter valid for all images may not be expected, because heterogeneity of the images may change due to sensor characteristics and time of acquisition.

Various studies have developed techniques to avoid subjectivity in setting segmentation parameters. For instance, Espindola et al. (2006) proposed an objective function that uses inherent properties of remote sensing data (spatial autocorrelation and variance) to support the selection of segmentation parameters. Similarly, Drăguţ et al. (2010) developed a tool for an objective estimation of scale parameters (ESP): it calculates the local variance of objects at different scale level, and by returning thresholds in rates of change of level of variance, it indicates the scale levels at which the image can be segmented in the most appropriate manner. The ESP tool has been used as it has been indicated useful when the targeted objects exhibit a single operational scale (Stumpf & Kerle, 2011), which is the case of charcoal production sites, and 37 has been chosen has scale parameter value.

The semi-automated detection method developed in eCognition Developer involved the creation of a classification rule-set based on parameters such as layer value, size, asymmetry, and roundness. Prior to segmentation, a low pass median filter was applied. The filter replaces the pixel value with the median value of neighboring pixels, therefore removing small random spatial variations. This creates a smoothened image that results in more homogenous image segments and avoid over segmentation.

Next, a search routine was constructed to explicitly filter only wanted features and to eliminate others. After the initial segmentation, a first reduction in the amount of segments was implemented by setting a threshold on the layer value to consider dark objects only. Typically, charcoal production sites appear as isolated dark spots with a defined size range, while other dark objects which can be present within the scene, like cloud shadows or other burnt areas, tend to cover much larger surface portions. Subsequent rules were introduced to exclude segments with similar values, but adjacent and outsized. Although further reduced to only segments within a specific range of sizes and layer values, the objects selection is still too broad at this stage. A final selection was thus applied with the definition of a more precise layer value interval, and also introducing rules that consider the roundish shape typical of charcoal production sites. The eCognition roundness feature describes how similar an image object is to an ellipse. It is calculated by the difference of the enclosing ellipse and the enclosed ellipse, with zero as ideal value. The progressive elimination of unwanted objects resulted in the identification and classification of charcoal production sites with a size ranging from a radius of 3 meters to 9 meters (as largest recorded). The roundness and size rules enabled to remove noise caused by confusion with shadows. In fact even in visual analysis, for small dark objects it is often difficult to discriminate between charcoal production sites and tree shadows, but the first generally tend to be rounder and larger than the second.

The mapped sites were also grouped per size, with a one meter radius increase from 3 m to 9 m (the maximum extent recorded). At present, the relationship between charcoal production site size and amount of trees burnt per site is not available, but such information would enable a more accurate tree loss estimation per site.

The thresholds for the described rules (digital number, size and roundness) are described in Table 1.

Table 1. Rule-set thresholds for WV-1 and QuickBird sensors (the second only used for change analysis as described in 2.2)

Sensor	DN Layer value				Radius Size	Roundness
	Pan	Green	Red	NIR		
WV-1 (0.5 m)	≤ 315	-	-	-	≥3m and ≤9m	≤ 0.45
QB (0.6 m)	-	≤ 260	≥ 165	≥ 255	≥3m and ≤9m	≤ 0.45

First on a 19 February 2013 WorldView-1 scene, a 1x1km plot with high concentration of charcoal sites was selected as pilot study area to develop the routine for detecting charcoal sites, and to verify its robustness. All charcoal sites within the pilot area were counted through photo-interpretation and used as ground truth substitutes to validate the procedure. The code identified 68 sites, out of the 75 sites previously visually counted within the pilot study area. All sites identified by the object oriented analysis were actual sites and no objects were misclassified. A sampling strategy was used to test the semi-automated method within the specific pilot area and, as a consequence of the good performance, the method was extended to the full study area.

A two-stage cluster sampling was implemented by building a grid of 1x1 km (clusters) to validate the capability of the developed algorithm in estimating the charcoal production sites across the entire satellite image coverage. A two-stage sampling is considered appropriate for studies where access to individual sample locations is particularly difficult (Köhl et al., 2006), a topical situation in a war-zone such as Somalia. The agriculture land was removed to leave only natural vegetation as considered population. A random sample of clusters was selected to cover 5% of the total natural vegetation area, and all charcoal production sites within this sample were counted by visual-interpretation.

2.2 Tree loss estimation and change analysis

The developed rule-set was applied both to the available 18 February 2011 and 19 February 2013 images, maintaining all thresholds unchanged, as the layer values for charcoal production sites were comparable both in terms of Digital Number (DN) and Top-of-Atmosphere reflectance (TOA). The DN values were transformed into TOA reflectance using the conversion parameters delivered with every WorldView (WV) product and located in the image metadata files (.IMD). For the QuickBird coverage of February 2012, both panchromatic band and pan-sharpened multispectral bands were tested in the analysis. First only the panchromatic band was considered, to compare with the WV-1 panchromatic results of 2013. The rule-set developed for the WV-1 analysis was adjusted only in terms of layer threshold, as TOA Reflectance values are different between WV-1 and QB.

After detection of the charcoal production sites for the whole area, the same assumptions used by Rembold et al. (2013) were applied to derive a tree loss estimation. Based on interviews and data from UNEP's report on the state of the Environment in Somalia (UNEP, 2005) it is assumed that 2 bags of charcoal are produced from a single average Acacia tree and that each production site produces an average of 40 bags of charcoal (capacity is 27 kg for each bag). Large trees can clearly produce more than 2 bags of charcoal, but there are sources confirming that the number of large Acacia trees found in Somalia is rapidly decreasing and that 1–2 charcoal bags per tree is a reasonable assumption (AFP, 2012). Therefore we decided to work with the 2 bags per tree hypothesis (equal to 20 trees per production site).

3. Results

The area available on all three dates was analysed and the results are as follows. On the February 2011 scene, 223 charcoal production sites were detected semi-automatically, including 177 of the 219 visually counted. For February 2012, of the 396 sites derived from semi-automation, 355 sites were correctly identified out of the 443 retained by visual interpretation. For February 2013, the semi-automated analysis resulted in 559 sites, of which 532 correctly matched the 613 recorded by visual interpretation.

Considering the semi-automated procedure only, out of the 223 sites classified for February 2011, 93 were still visible on 2012 scenes. 395 sites were present in February 2012, of which 302 represent new sites. In February 2013, 559 sites were detected, with 247 that were not present neither in 2012 nor 2011. Sites present on two dates have an average smaller size in the more recent one, which was expected as sites tend to disappear once dismissed and is visible also for some sites in Figure 2, which appear slightly larger in 2012 than in 2013.

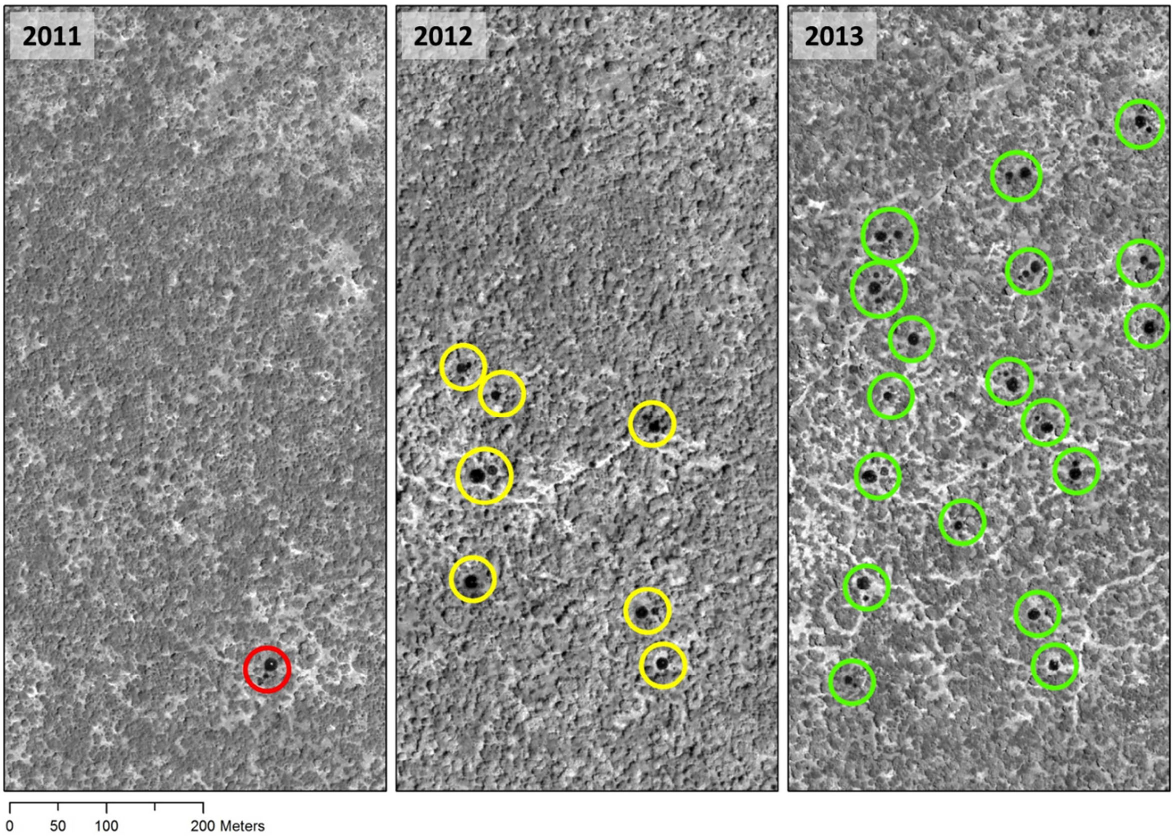

Fig. 2. Subset of the study area in 2011 (left), 2012 (centre) and 2013 (right) showing the increase of charcoal production sites (circles). *Image Copyright DigitalGlobe (for the 2013 image).*

The resulting producer's accuracy for 2011 was 79.4%, while the user's accuracy was 80.8%. After a visual inspection, the reason of low producer's accuracy could be easily explained by the visual identification of two areas with signs of wildfire: the brightness values of burnt vegetation mislead the software interpretation, while the visual interpreter can still make the distinction based on a broader context analysis.

For 2012, the semi-automatic procedure applied to the panchromatic band resulted in both poorer user's and producer's accuracy (61.0% and 61.9% respectively), if compared to WV-1 analysis. This was due to the difficulty in distinguishing tree shadow values from charcoal production sites values using one band only due to a lower viewing angle. The following step was introduced to explore the advantages of using the multispectral bands values, available for the QuickBird scenes, by including in the rule-set thresholds for individual bands. Both multispectral and principal components analysis were tested in search of the best results. Adapting the rule-set to test the potential of principal components analysis resulted in a user's accuracy of 92.1% and a producer's accuracy of 68.6%. The semi-automatic detection based on the use of multispectral bands gave a comparable user's accuracy of 89.9%, but a better producer's accuracy, 80.1%.

For February 2013, the same rule-set used on 2011 images was applied, and gave an overall user's accuracy of 95.2% and a producer's accuracy of 86.8%.

For each year, two buffers of respectively 100 m and 200 m were created around the detected charcoal production sites. In each case at least 93% of the charcoal production sites recorded only by the photo-interpreter and not by the semi-automatic method, can be found within a buffer of 100m of the semi-automatically detected sites, and over 96% within 200m.

The rule-set was also applied to the full area available for February 2013, and revealed 6203 charcoal production sites (Fig. 3). Based on the two-stage cluster sampling applied, the resulting producer accuracy was 93.5%, meaning that a very high percentage of all polygons classified as charcoal production sites are indeed charcoal production sites on the ground. However, the user's accuracy was only 77.0%. While the semi-automated detection does not provide the full number of sites, it gives a clear indication on the areas affected by charcoal production. In fact, 90.7% of visually counted sites fall within a buffer of 100 m around the semi-automatically detected sites, and 97.1% within a buffer of 200 m.

The last step of the study was a tree loss assessment. Based on a trees density of 3400 per square kilometre and 20 trees used per production site (Rembold et al., 2013), a tree loss of 8.63% was estimated for the change detection area over the period 2010-2013 corresponding to 15,434 trees. A tree loss estimation was also calculated for the larger area available for 2013 only (745 km^2) and projected a tree loss of 124,060 trees, equal to 4.90% of the tree cover. In this case, we just consider the sites visible in 2013 and have no evidence of earlier sites that have already been covered by vegetation, meaning that the figure is underestimated.

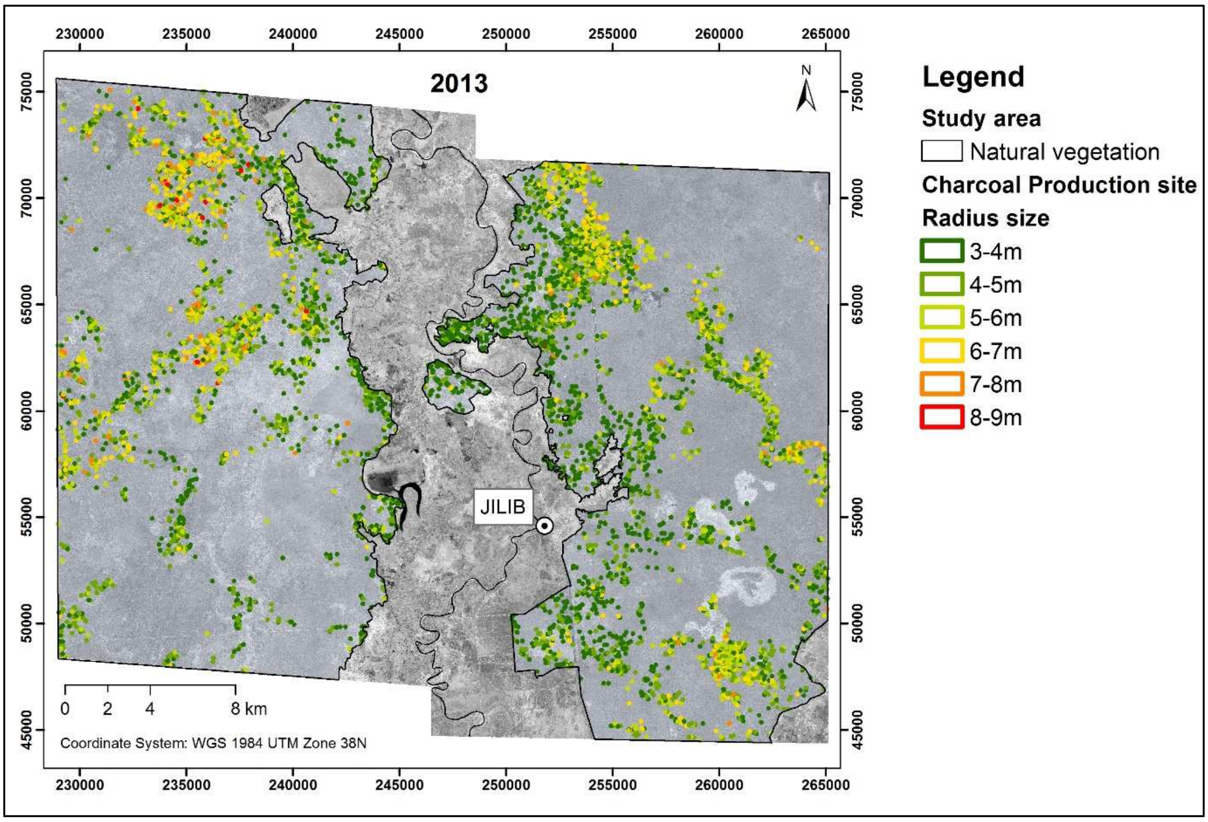

Fig. 3. Charcoal site distribution 2013. *Image Copyright DigitalGlobe.*

4. Conclusions and discussion

The results clearly confirm the high level of suitability of VHR imagery for charcoal production monitoring in Southern Somalia. They also make it clear that for larger areas and consequently larger volumes of data, an automatic object detection approach is more powerful and accurate than visual interpretation affected by high levels of subjectivity. Furthermore the automatic method allows also the differentiation of charcoal production site size which could be used to refine the tree loss estimate assuming that better information can be retrieved for understanding the relationship between production site size and volume of produced charcoal. One small disadvantage as compared to visual interpretation is that since the rules have to be strict and homogeneous, with the automatic procedure it is not possible to detect older sites which show less contrast with the surrounding environment and have been partially overgrown by grass. However, it has to be noted, that due to the large variability of older sites, such an interpretation risks to be highly subjective even if done by expert photo interpreters.

The accuracy of the developed method depends on the quality and the characteristics of the images. Panchromatic scenes obviously present the limitation of offering only one layer to the analysis. The results can be affected by atmospheric condition and viewing angle, therefore making it potentially difficult to automatically discern objects with similar spectral and spatial characteristics, as in the case of tree shadows and charcoal production sites. For the present study, the illumination and atmospheric conditions of acquired panchromatic WorldView-1 imagery were ideal, allowing not to incur in such potential problems (except for a naturally burnt area on the 2011 scene, where a rapid visual inspection of the results can easily correct for such errors). The availability of a multispectral scene allowed for exploring the potential of adjusting the rule-set to profit of more information provided by multiple bands. User's accuracy generally increases by using multi-spectral imagery as compared to panchromatic images as expected. However the WV-1 panchromatic imagery used for this study also performed well in a rapid detection of charcoal production sites. Producer's accuracy is very high in both cases, proving that the risk of confusing charcoal production sites with other ground features is low.

As fieldwork for gound-truthing is unfeasible at present due to high security risks, the accuracy assessment depends on visual interpretation, which in turn can be subjective depending on visual interpreter skills and perception. The semi-automated procedure performs well, both objectively identifying the majority of total charcoal production sites and, through the use of a simple buffer, accurately locating the production areas.

Concerning the spatial distribution of the sites, it appears that smaller ones (3 to 4 m radius) are mainly concentrated in the proximity of agriculture areas. That would suggest a charcoal production on a smaller scale, probably for domestic uses, rather than an industrial production directed to export, or at tree scarcity due to logging in past years. This pattern seems to confirm that recent large scale charcoal production, as the one promoted by Al Shabaab, concentrates first in more remote areas where tree density is higher. But this hypothesis is hard to confirm without ground evidence.

The tree loss estimation was done by using the same assumptions presented by Rembold et al. in 2013 for a similar area. These assumptions, based on local experts' interviews are quite simplistic but aim mainly at providing a key range of tree loss in the area due to charcoal production. It is clear that any mistake in those assumptions would lead to a large mistake in the overall tree loss. For any more detailed and accurate tree loss estimation, especially in relation to the production site size as the one provided by the currently presented methodology, it would be of paramount importance to verify the basic relationships between number of trees burnt per site and amount of charcoal produced as well as the original tree density in the area.

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