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Comparing Accuracy of Three Remote Sensing Methods to Evaluate Soil Impact Related to Forest Operations†

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Abstract: Monitoring soil impacts related to forest operations is crucial to reach the sustainable forest management goal. On the other hand, field relieves to assess such kind of impacts are usually costly and time consuming. Therefore, the possibility of using remote and proximal sensing technologies to analyze forest soil impacts could be very helpful for forest managers. According to this, the aim of the present work was the evaluation of reliability of three different remote sensing tools for the assessment of soil impact related to forest operations. Study area consisted in an oak coppice located in the Municipality of Castel Giorgio (Terni District, Central Italy). The different tested technologies were Sentinel-2, Google Earth and Unmanned Aerial vehicle equipped with RGB sensor. After forest utilization, images of the study area were obtained by the above-mentioned systems, and a photo-interpretation process allowed to identify the skid trails pattern opened by the operators during the extraction of timber. The three theoretical skid trails patterns were compared with the real one, obtained by field relief with GNSS technology. The obtained results showed that all these systems still need some improvements for an effective application in Italian forest sector, concerning soil impacts evaluation after forest operations.

Keywords: Google Earth; Unmanned Aerial Vehicle; GNSS; GIS; Central Italy

1. Introduction

One of the main goals of sustainable forest management is making sure that forest utilization meets the requirements of all three pillars of sustainability [1]. A key issue to achieve this goal is carrying out forest operations with the aim to minimize the negative impact of harvesting, without limiting work productivity as well as assuring safety of forest workers [2–4]. Focusing in particular on soil impact related to forest utilization, a major factor in damaging soil is machinery traffic, which is able to cause compaction, soil mixing and topsoil removal [5–8].

Ground reduction and damage to regeneration caused by silvicultural treatments and forest operations remain therefore a key topic [9].

For what said before, monitoring soil impacts related to forest operations is crucial. The current monitoring process of impacts to soil is mainly performed through soil samples collection and analysis, or measured using specific instruments, such as penetrometer and scissometer [10]. These methods are however time consuming and costly [11].

A possible solution to this issue concerns the application of remote and proximal sensing techniques in order to assess the spatial distribution of soil impacts [11,12]. In this regard, scientific research has been putting effort into assessing the efficiency of various technologies for the evaluation of soil microtopography changes, in relation to forest machinery traffic. In particular, terrestrial laser scanning (TLS) gave good results [13,14], while airborne laser scanning (ALS) showed a good performance in similar tests, not performed on forest environment [15], as well as in the identification of soil moisture in order to avoid forest utilization to be carried out in difficult conditions [12]. On the other hand, the effectiveness of remote sensing techniques for the evaluation of soil impacts has not been widely studied yet.

The goal of the present work was to properly evaluate the effectiveness of some remote sensing and proximal sensing techniques for the assessment of soil impacts related to forest operations, with particular focus on the amount of surface area impacted by machineries during extraction operations. Three different approaches have been considered to detect the tracks of machinery passes: Google Earth images, Sentinel-2 images and high-definition images provided by an unmanned Aerial Vehicle (UAV) equipped with RGB sensor. A GNSS field relief was considered as a control in order to make a comparison with the obtained results.

2. Materials and Methods

2.1. Study Area

The study area was located in Castel Giorgio municipality (Umbria, Italy). Selected stand was coppice forest of two species:turkey oak (*Quercus cerris* L.) and chestnut (*Castanea sativa* Mill.) with a surface area of about 16 ha. The average height is 580 m a.s.l. with a prevalent slope of 10% and a maximum slope of 35% (Figure 1). Coppicing intervention, with the release of 80 standards per hectare, were performed in 2017-2018. Harvesting system consisted of Tree Length System (TLS), with motor-manual felling by chainsaw and extraction by wheeled grapple skidder.

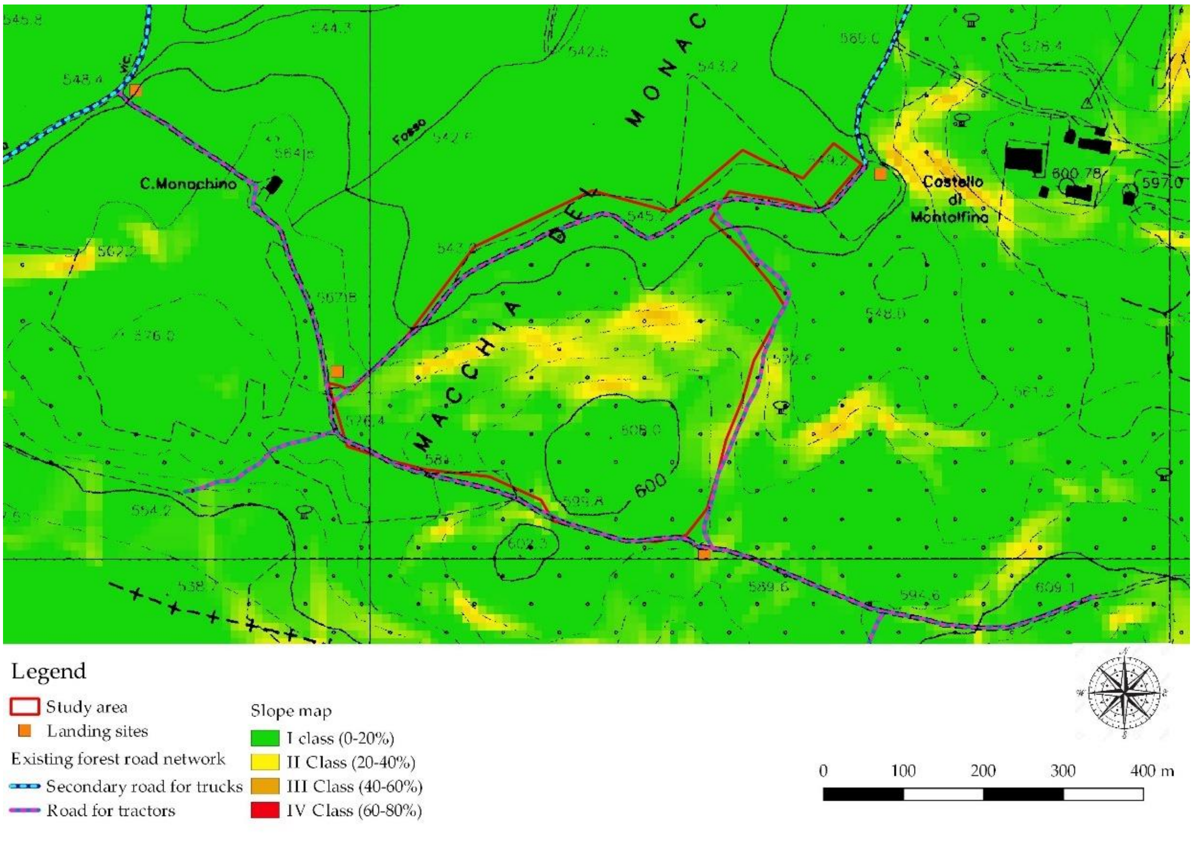

Figure 1. Study area, existing forest road network and landing sites overlaid on the slope map.

2.2. Field Relieves

After the end of the forest utilization, a GNSS relief with a Trimble Juno handheld receiver [16] was used for the identification and recording of the all skid trails opened during the extraction operation; the width of each skid trail has been recorded through measuring it with a measure tape.

After four months, the relief with UAV took place. The limited duration of the battery made possible the survey of just four ha. In this area, the relief with RGB sensors allowed to obtain high-resolution raster images (50 cm pixel).

2.3. Detection of Impacted Surface

The tracks recorded through the GNSS receiver were imported in *Quantum GIS 2.18* software [17] in order to be converted into shapefile format for further analysis.

Google Earth images of the area were imported into QGIS software interface through the plugin "Quick Map Service" and, by a photo-interpretation process, a line shapefile bearing the "new" skid trails detectable through satellite images (i.e. skid trails not previously present and reported in Figure 1) was created.

A similar procedure was applied for the high-resolution images provided by the UAV.

For what concerning Sentinel-2 satellite images, they were firstly downloaded from the dedicated website [18] and imported in QGIS, then a real-color image of the area was created to perform the photo-interpretation process, as applied for the other investigated systems.

It is important to underline that for Google earth and Sentinel-2 images it was possible to investigate all the study area, while for the UAV the analysis was limited to only 4 ha.

After processing the shapefiles of the various theoretical skid trails network, twenty virtual sample plots with round shape of 1256 m^2 each (radius 20 m) were randomly identified within the intervention surface, to make possible the comparison between the real skid trails network (obtained by GNSS relief) and the theoretical network obtained by Google earth and sentinel-2 images . A similar procedure was applied for the UAV skid trails network, but the dimension of the virtual sample plots was reduced to 314 m^2 each (radius of 10 m). Within each virtual sample plot, the skid trails length was identified in order to estimate the forest road density (m ha^{-1}) and the impacted surface (%), this last considering the average width of skid trails detected in the previous field relief.

Dependent samples T-test was performed to detect the presence of statistically significant differences between the control skid trails, obtained through GNSS, and the skid trails obtained through the different investigated approaches.

3. Results

The first result of the work concerns the remark about the uselessness of Sentinel-2 images for impacted surface detection during forest operations. Indeed, the 10 m pixel of Sentinel-2 images does not allow the skid trail identification on the pattern, as reported in Figure 2.

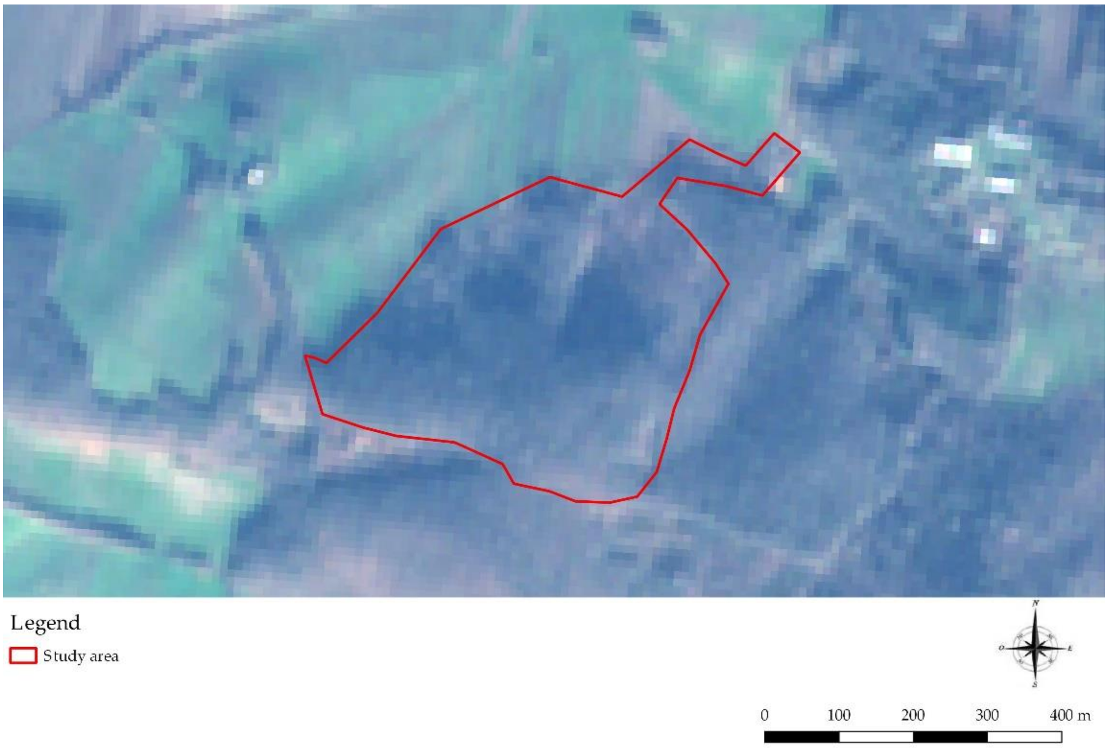

Figure 2. Study area overlapped on a real color image obtained by Sentinel-2. As it is possible to notice, the 10 m pixel dimension do not allow the identification of the skid trails pattern.

The comparison between Google Earth skid trails pattern (GE) and the control pattern (GNSS) showed that there was bigger average impacted surface detected and bigger road density when using GNSS (Table 1, Figure 3).

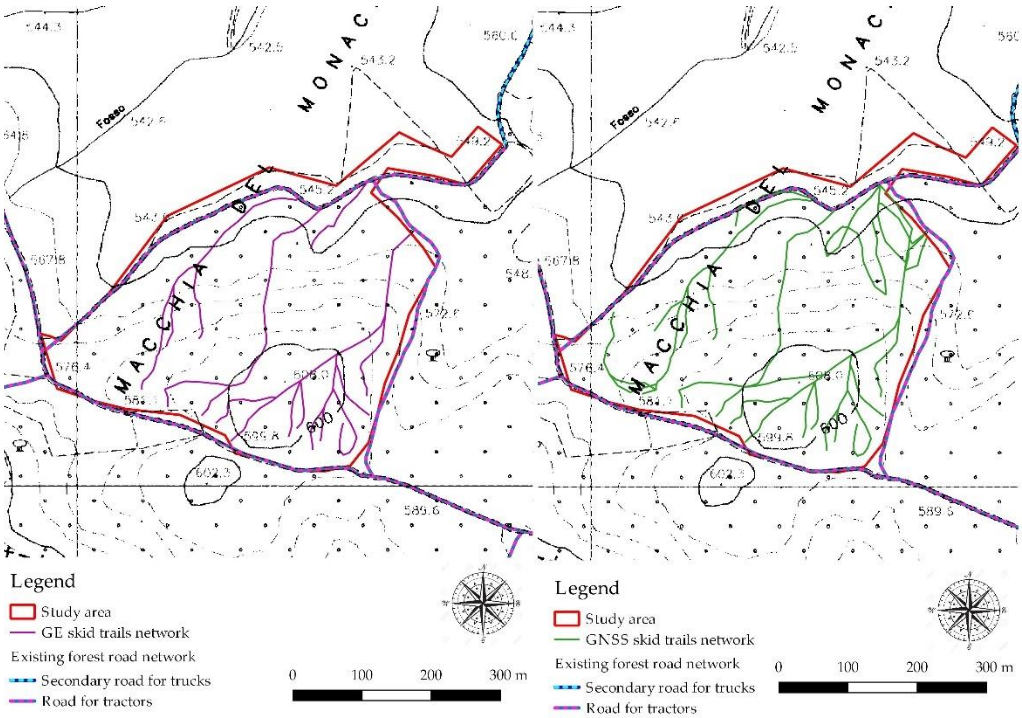

Figure 3. Comparison between skid trails patterns identified with GE (on the left) and GNSS (on the right).

Table 1. Results of the T-test for the comparison between the skid trail pattern detected through Google Earth images (GE) and the control one (GNSS).

	GE		GNSS	
	Avg.	St.Dev	Avg.	St.Dev.
Impacted surface (%)*	7.96	6.41	10.58	7.56
Road density (m ha^{-1})*	227	183	302	216

* Represents a statistically significant difference at p>0.05 according to dependent samples T-test.

As it is possible to notice, there is a significant underestimation of both the impacted surface and forest road density, according to the results of dependent samples T-test.

The comparison between the skid trails pattern obtained through RGB sensors and unmanned aerial vehicle (UAV) showed that there was bigger average impacted surface detected and bigger road density when using UAV (Table 2, Figure 4).

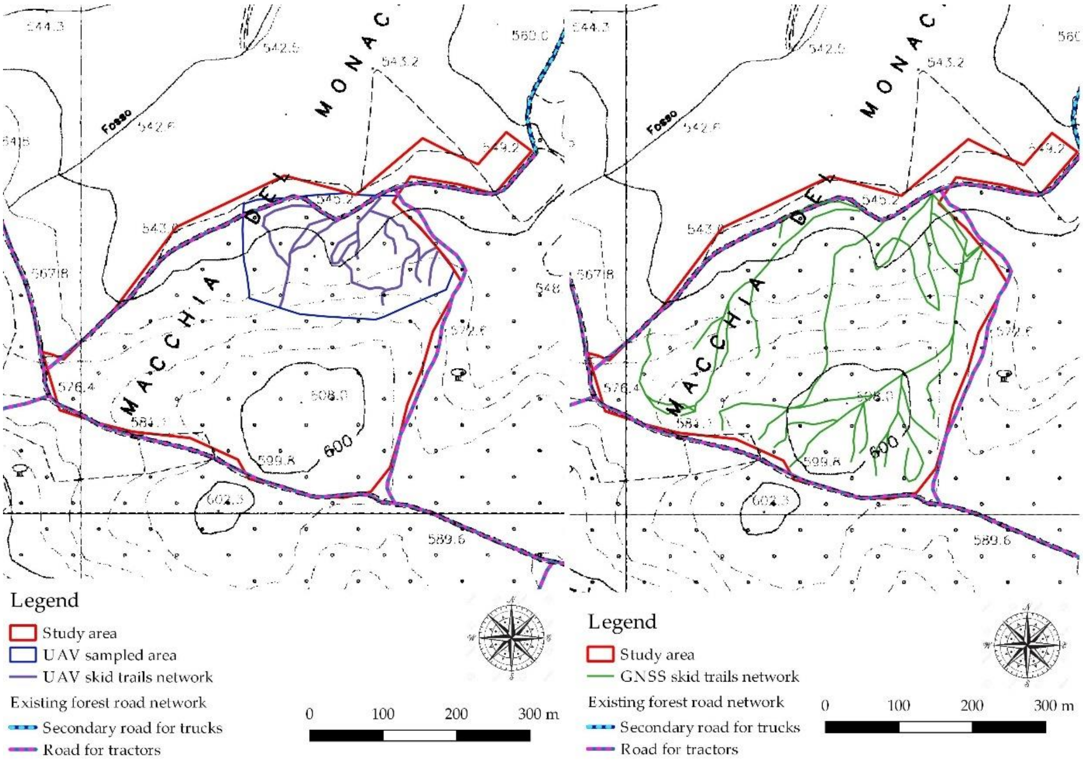

Figure 4. Comparison between the skid trails pattern identified with GE (on the left) and GNSS pattern (on the right).

Table 2. Results of the T-test for the comparison between the skid trails pattern detected through Google Earth images (GE) and the control one (GNSS).

	UAV		GNSS	
	Avg.	St.Dev	Avg.	St.Dev.
Impacted surface (%)*	14.04	12.34	10.58	7.56
Road density (m ha^{-1})*	401	353	302	216

* Represents a statistically significant difference at p>0.05 according to dependent samples T-test.

In contrast to what reported for GE, UAV showed a significant overestimation of both the impacted surface and forest road density, in comparison with the control skid trail pattern.

4. Discussions and Conclusions

The first evidence, which was predictable, is that Sentinel-2 images, which are the highest resolution images freely available with short time lag (few days), are not suitable for the detection of forest soil impact related to machinery passing. The 10-m pixel is indeed not enough accurate to detect the tracks. So, even if Sentinel-2 is a very powerful tool for several forest application, it is not effective in soil impact monitoring.

As a consequence, to deal with remote sensing in forest utilization, higher definition images are needed, which are generally not free to use.

A partial exception consists in Google earth images, which are freely available, even if the updating time is about 1-2 years, which is obviously a substantial limit to carry out the monitoring of forest soil impacts.

It is therefore needed to have Google Earth images close in time to the utilization, and this is not always possible.

On the other hand, even if the statistical analysis revealed a significant underestimation of the impacted surface in comparison with the control skid trails pattern, Google Earth images seem to be a useful instrument. Moreover, it is important to underline that for the forest yard in exam, a high mechanization level was implemented, consequently making easier the skid trails identification because of the substantial dimensions of machineries used. According to this, it could be interesting to evaluate the performance of Google Earth images also in small scale mechanization forest yards.

For what concerning the UAV with RGB sensor, it certainly revealed to be an interesting instrument, even if it with some limitations. The obtained results showed an overestimation of the impacted surface, so a few actually non-existing skid trails were identified as machinery tracks.

To avoid this, it is important to improve the know-how of the operator within the process of photointerpretation, as well as investigating the performance of different sensors, for example LiDAR. Moreover, the main limit consisted in the limited battery life which, currently, does not allow the relief of areas in accordance with the typical dimension of forest yards in Central Italy.

To summarize:

- Currently, the best remote sensing system to monitor soil impacts related to forest utilization consists of high-resolution satellite images, which however are not freely available according to the needed short time lag, and considering that Google Earth does not ensure enough short time lag
- UAV is a very interesting technology, which however needs to be further improved to be efficient in the conditions of Central Italy forestry
- GNSS field relief, even if costly and time consuming, is currently the best solution to monitor soil impacts related to forest operations, as reported also by Ellis et al. (2016) [19]

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