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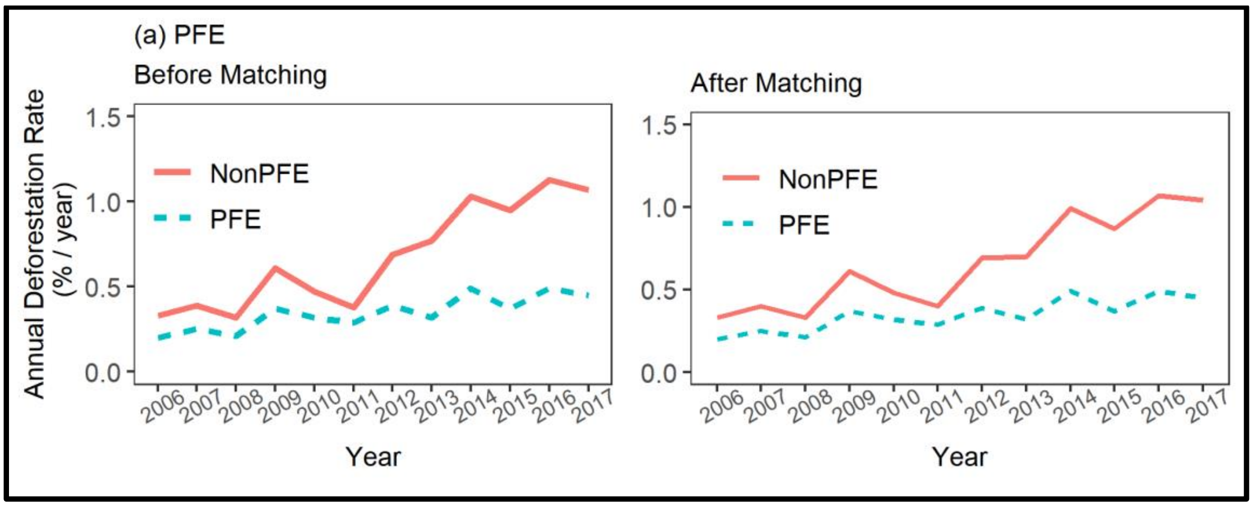
A Country Scale Analysis on the Effectiveness of Land-use Zoning on Reducing Deforestation in Myanmar



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Country Scale Analysis on the Effectiveness of Land-use Zoning on Reducing Deforestation in Myanmar

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Abstract

Designating different land-use zonings in forest land with various legal restrictions is a practically implemented way to control deforestation and keep the forests in long-term around the world. In Myanmar, forest lands are managed by categorizing into various land-use zonings such as Reserved Forest (RF), Protected Public Forest (PPF) and Protected Area (PA). However, due to an increased deforestation, it is crucial to understand the conservation performances of forest land-use zonings. Here, we evaluated the effectiveness of land-use zonings in reducing deforestation between 2006 and 2017 in Myanmar at country scale comparing with non-forest land. In this study, the analysis was conducted using propensity score matching which helps to minimize the effect of the non-random distribution of land-use zonings. The results showed that forest land-use zonings such as RF, PPF and PA had a lower deforestation than outside of forest land, and thus, we concluded that designating land-use zonings in forest land is effective in reducing deforestation. However, we found that there was an increased trend of annual deforestation between 2006 and 2017 in both forest land, especially RF and PPF, and outside of forest land. Thus, further efforts should be undertaken to mitigate the increase of deforestation in RF and PPF.

Key words: Avoided deforestation, Average Treatment Effect on the Treated, Global Forest Change Data, Propensity Score Matching, Spill-over

မြေအသုံးချမှုဇုံများ ခွဲခြားသတ်မှတ်ခြင်းဖြင့် သစ်တောပြုန်းတီးမှု လျော့နည်းစေခြင်းအပေါ် သက်ရောက်မှုအား ဆန်းစစ်ခြင်း

စာတမ်းအကျဉ်း

သစ်တောမြေများတွင် အမျိုးမျိုးသော မြေအသုံးချမှုဇုံများ သတ်မှတ်၍ သစ်တောများ စီမံအုပ်ချုပ်ခြင်းသည် သစ်တောပြုန်းတီးမှုကိုထိန်းချုပ်နိုင်ရန်နှင့် သစ်တောများ ရေရှည်တည်တံ့စေရေးအတွက် ကမ္ဘာတဝှမ်းတွင် လက်တွေ့ကျကျ အကောင်အထောင်ဖော် ဆောင်ရွက်လျက်ရှိသော နည်းလမ်းတစ်ခု ဖြစ်ပါသည်။ မြန်မာနိုင်ငံရှိ သစ်တောမြေများတွင် ကြိုးဝိုင်းတော၊ ကြိုးပြင်ကာကွယ်တောနှင့် သဘာဝထိန်းသိမ်းရေးနယ်မြေများ သတ်မှတ်၍ ကာကွယ်ထိန်းသိမ်း စီမံအုပ်ချုပ်လျက်ရှိပါသည်။ သို့သော်လည်း တိုးပွားလာသော သစ်တောပြုန်းတီးမှု အခြေအနေများကြောင့် သစ်တောမြေများတွင် မြေအသုံးချမှုဇုံများ သတ်မှတ်အုပ်ချုပ်ခြင်း၏ သစ်တောပြုန်းတီးမှု လျော့နည်းစေခြင်းအပေါ် သက်ရောက်မှုအား ဆန်းစစ်မှုများပြုလုပ်ရန် အရေးကြီးလာပါသည်။ ထို့ကြောင့် ဤစာတမ်းတွင် မြန်မာနိုင်ငံရှိ သစ်တောမြေအသုံးချမှုဇုံများတွင် ၂၀၀၆ ခုနှစ်မှ ၂၀၁၇ ခုနှစ်အတွင်း သစ်တောပြုန်းတီးမှု အခြေအနေအား Propensity Score Matching အသုံးပြု၍ မြေအသုံးချမှုဇုံပြင်ပရှိ အခြေအနေနှင့် နှိုင်းယှဉ်၍ ဆန်းစစ်ခဲ့ပါသည်။ ရလဒ်များအရ သစ်တောမြေအသုံးချမှုဇုံများဖြစ်သော ကြိုးဝိုင်းတော၊ ကြိုးပြင်ကာကွယ်တောနှင့် သဘာဝထိန်းသိမ်းရေးနယ်မြေများတွင် သစ်တောနယ်မြေပြင်ပထက် သစ်တောပြုန်းတီးမှု နည်းပါးသည်ကို တွေ့ရှိပါသည်။ ထို့ကြောင့် သစ်တောမြေများတွင် မြေအသုံးချမှုဇုံများခွဲခြား၍ သစ်တောစီမံအုပ်ချုပ်ခြင်းသည် သစ်တောပြုန်းတီးမှု လျော့နည်းစေခြင်းအပေါ် အကျိုးသက်ရောက်မှုရှိသည်ဟု ကောက်ချချက်နိုင်ပါသည်။ သို့သော်လည်း ကြိုးဝိုင်းတောနှင့် ကြိုးပြင်ကာကွယ်တောများတွင် နှစ်စဉ် သစ်တောပြုန်းတီးမှု အခြေအနေ တိုးပွားလာသည်ကို တွေ့ရှိရပါသဖြင့် သစ်တောပြုန်းတီးမှုအား ထိန်းချုပ်နိုင်မည့် နည်းလမ်းများအား ဆောင်ရွက်သွားရန် လိုအပ်ပါသည်။

A Country Scale Analysis on the Effectiveness of Land-use Zoning on Reducing Deforestation in Myanmar

1. Introduction

Forests providing a variety of ecosystem services are the most critical renewable resources to the planet and a cost-effective way to mitigate climate change. Therefore, it is important to secure the sustainable management of invaluable forest resources because they play a key role for income, livelihoods and well-being for human being, and climate change mitigation (FAO., 2018). However, according to the Global Forest Resources Assessment (FRA) 2015, the extent of global forest areas decreased about 3% between 1990 and 2015, while the annual rate of net forest loss was falling twice (FAO., 2016). Tropical regions especially experienced the higher forest cover loss (Hansen et al., 2013b) and deforestation in tropical region became has been global concerns (DeFries et al., 2005; Heino et al., 2015; Malhi et al., 2014). Thus, interventions to combat deforestation in tropical forests became the core of global environmental policy.

Land-use zoning, which is a segmentation of the landscape into units, is a practically implemented way to control deforestation. Around the world, permanent forest land is a tool for maintaining forest areas in perpetuity. According to the Global Forest Resources Assessment (FRA) (2015), about 2.2 billion ha of forests are permanent forest land and half of these are found in tropical regions (FAO., 2016). Within permanent forest land, forest lands are categorizing into different zones based on different purposes such as forest protection and forest production. Thus, forest lands can be allocated to various categories of land-use zones such as reserved forest, protection forest, community forest, etc., with various levels of restriction. Due to various levels of restrictions in land-use zones, forest conservation performances may differ among land-use zones. Thus, it is crucial to understand the effectiveness of each zoning approach on reducing and combating deforestation with empirical evidence because it may be useful to provide policymakers with evidence regarding which land-use zones are the most effective and efficient ones in reducing deforestation.

Previous studies evaluating the forest conservation effectiveness of land-use zoning mainly focused on protected area (PA), and such studies implied that PA is effective to reduce deforestation (Andam et al., 2008, 2013; Bowker et al., 2017; Maharaj et al., 2019; Oldekop et al., 2019). However, the results revealed that the effectiveness of PA may vary across landscape, locations, types, and enforcement. Similarly, the studies of community forests (Lonn et al., 2019; Oldekop et al., 2019; Santika et al., 2017, 2019) and production forests (Bruggeman et al., 2015, 2018; Gaveau et al., 2013; Kukkonen & Tammi, 2019) around the world also showed that some are effective in forest conservation but some are not. For example, in Cambodia, community forests are effective in reducing deforestation (Lonn et al., 2019), however, higher deforestation was found inside community forests in Laos (Kukkonen & Tammi, 2019). Therefore, there is a need to evaluate the effectiveness of each land-use zoning at each location.

Myanmar is one of the tropical countries and has high forest cover in Southeast Asia (Yang et al., 2019). However, according to Global Forest Resources Assessment 2015, Myanmar has been recognized as third greatest deforested country in the world (FAO., 2016), though forest conservation efforts have been increased since 20 years ago (Wang & Myint, 2016). The increasing forest cover loss in Myanmar make a concern to the world (Wang & Myint, 2016) and is challenging to the effectiveness of Myanmar's forest conservation policy. In Myanmar, forest lands are designated as Reserved Forest (RF), Protected Public Forest (PPF) and Protected Areas (PA) to manage the forests systematically leading to the sustainable use of forest resources and biodiversity conservation. In this study, we defined RF, PPF and PA as Permanent Forest Estate (PFE) and outside of RF, PPF and PA as non-PFE. As of August 2019, about 30% of Myanmar was covered with the extent of PFE (RF + PPF + PA). The Myanmar government plans to expand the PFE (RF + PPF + PA) to 40% of the country total area by 2030 according to 30 years National Forestry Master Plan (2001-2030) and Myanmar's Intended Nationally Determined Contribution (INDC). However, the forest conservation effectiveness of PFE in Myanmar is still unclear. Therefore, here, we investigated the effectiveness of the PFE as a whole and each land-use zone of PFE such as RF, PPF and PA separately using country scale datasets.

2. Objectives

The purpose of this study is to identify deforestation inside and outside PFE and to understand the conservation effectiveness of the PFE as a whole and each land-use zone of PFE comparing with non-PFE after balancing non-random distribution of PFE.

3. Study Area

Myanmar is a country with tropical climate located in Southeast Asia. The total area and population are 676,577 km^2 and 54.3 million, respectively. Myanmar has a unique biodiversity (Reddy et al., 2019) and is third largest forested country in the Greater Mekong Sub-region. According to FRA 2015, about 42.92% of the total country area is covered with forests (FAO., 2014) and it has different types of forests ranging from alpine to mangrove (Leimgruber et al., 2005).

In Myanmar, forests are in PFE and non-PFE. Within PFE, forests are managed by assigning land-use zones such as Reserved Forest (RF), Protected Public Forest (PPF) and Protected Area (PA). In this study, we focused on PFEs which were constituted in or before 2005. We used the information and boundaries for PFEs which were acquired from Forest Department of Myanmar. We excluded the PFEs which have lack of information of constitution year. In addition, the PAs which are aimed for lake or marine conservation and the PFEs which are not formally authorized were also excluded from the analysis. In total, 996 PFEs, approximately 75% of total PFEs established before July 2017, were included in the final dataset (Figure 1).

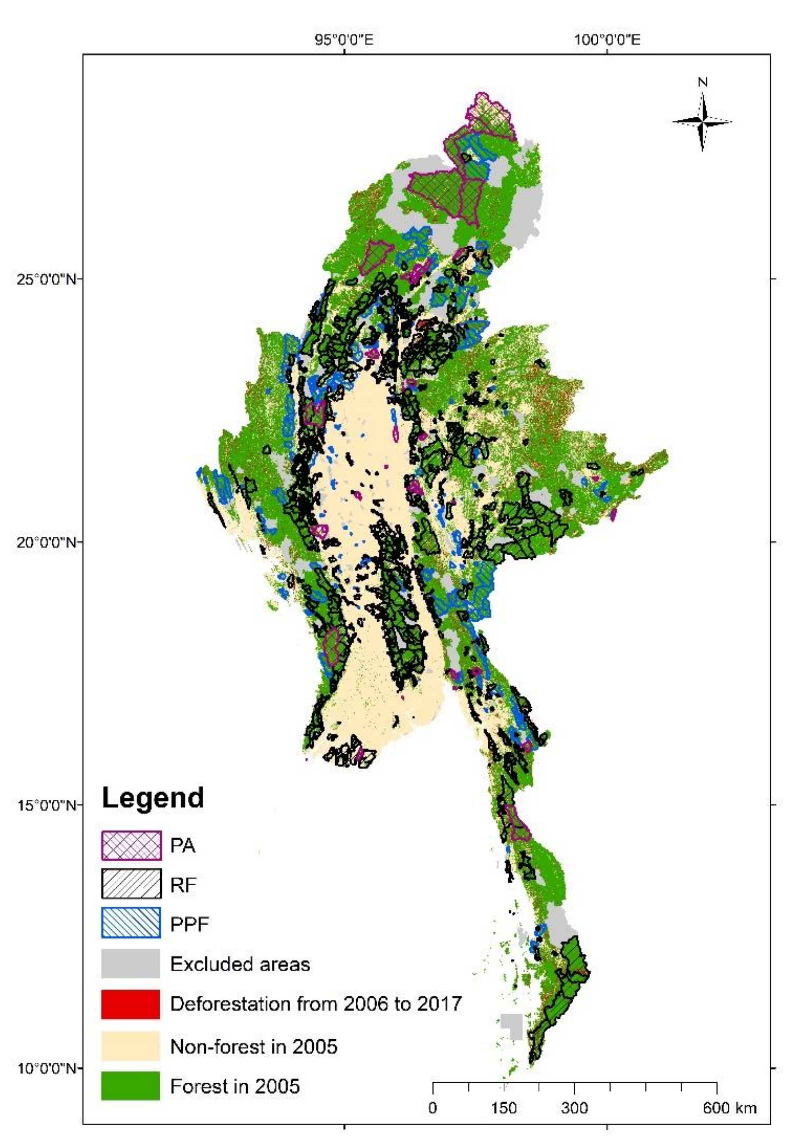

Figure 1. Location of land-use zones of PFEs with forest cover in 2005 and deforestation from 2006 to 2017. Forest cover extent and deforestation layer were downloaded from Global Forest Change website (Hansen et al., 2013a)

4. Methodology

The areas subjected to designate and assign as PFE are not randomly distributed but are often distributed in locations with high forest cover or lower/higher deforestation pressures. Because of disproportionate locations of land-use zones, there may be biased result (i.e. over- or under-estimation of the effectiveness) in evaluating the effectiveness using conventional method which simply compares forest cover changes inside and outside land-use zones of PFEs (Andam et al., 2008; Cuenca et al., 2016; L. N. Joppa et al., 2008; L. N. Joppa & Pfaff, 2009; L. Joppa & Pfaff, 2010). Thus, it is important to control confounding factors which might affect the likelihood of deforestation inside and outside PFEs. Previous studies have widely used matching method to reduce the biases from simple comparison (Andam et al., 2008; Bruggeman et al., 2015; L. N. Joppa & Pfaff, 2011; Lonn et al., 2019; Nelson & Chomitz, 2009; Oldekop et al., 2019; Santika et al., 2017, 2019). Matching is a method to find matched pairs between protected and unprotected which have similar land characteristics (Heino et al., 2015; L. N. Joppa & Pfaff, 2011; Kere et al., 2017). There are various types of matching approaches such as covariate matching, propensity score matching, genetic matching, etc. (Sekhon, 2011).

4.1. Treatment and control variables

First, we evaluated the forest conservation effectiveness of the PFE as a whole compared with non-PFE, defining PFE as treatment and non-PFE as control. Then, we analyzed the effectiveness of each land-use zone of PFE (RF, PPF and PA) by comparing with non-PFE, and we defined RF, PPF and PA as separate treatments and non-PFE as control. Because there might be a spill-over (leakage) due to the constitution of PFE, we also measured the spill-over (leakage) around PFE. In this case, we defined non-PFE located within 5 km of the boundary of PFE as the treatment and the control group comprised non-PFE that was located more than 5 km from PFE.

4.2. Outcome variables

In this study, deforestation data was extracted from Global Forest Change Data (GFCD) developed by Hansen et.al (Hansen et al., 2013b). GFCD consists of three main layers such as tree cover extent in 2000 representing 0-100% tree cover in each pixel, annual loss layer 2001-2017 and gain layer 2001-2017. Due to lack of annual gain information, we ignored the information of gain in this study.

In GFCD, there is no information about forest cover. Therefore, the users must apply the knowledge of forest cover from other sources. One practical option is to create forest cover map using tree cover threshold. In this study, we used 40% tree cover threshold to define forests according to our previous study (Lwin et al., 2019), and we defined the forest in 2000 where a pixel had at least 40% tree cover using tree cover extent of the GFCD. Because we selected the RF, PPF and PA which were established in and before 2005, we defined forest in 2005 when a forest pixel in 2000 did not overlap with forest loss from 2001 to 2005.

In this study, we defined “Deforestation” and “No deforestation” as outcome variables. “Deforestation” was defined when forest pixels in 2005 overlapped with forest loss from 2006 to 2017. “No deforestation” was defined when forest in 2005 did not overlap with forest loss from 2006 to 2017. Thus, outcome variable was binary “(1) Deforestation” and “(0) No-deforestation”. Pixels of 30 m were the unit of our analysis.

4.3. Confounding variables

We selected the confounding variables which might affect the likelihood of deforestation and the selection of location of PFEs based on previous studies (Htun et al., 2010; Lonn et al., 2019; Mon et al., 2012) and data availability. The variables included in this study were elevation, slope, distance to the nearest road, distance to the nearest river, distance to the nearest railway, distance to the nearest town, and population density. For elevation data, ASTER GDEM (U.S. Geological Survey, 2019) which is a 30-m resolution DEM, was applied and slope was generated from ASTER GDEM. The layers of road, river, town and railway were downloaded from the Myanmar Information Management Unit (MIMU). The layer of population density at township level was from Department of Population, Myanmar.

4.4. Analysis

We evaluated the effectiveness of the PFE as a whole and each land-use zone of PFE such as RF, PPF and PA separately using a sampling strategy. For each analysis, we randomly selected one million forest pixels (shown in Table 1). In this study, we used propensity score matching (hereafter matching) using nearest neighbor approach with caliper. We used "MatchIt" package of R version 3.5.1 to conduct PSM (Ho et al., 2011). PSM finds the matched observations between treatment and control, and we also applied the caliper, which is the distance between matched observations for each land characteristics (Andam et al., 2013), because there might be poor quality of balance in matching without caliper (Lunt, 2014). Based on deforestation happened in matched observations between treatment and control, Average Treatment Effect on the Treated (ATT) for deforestation which is the difference of the probability of being deforested (Kere et al., 2017) was estimated using regression.

Table 1. Number of treated and control forest pixels for Propensity Score Matching

Analysis	Treatment	Treated pixels	Control	Control Pixels	Matched pairs
PFE vs Non-PFE	PFE before 2005	375,474	Non-PFE	624,526	375,474
RF vs Non-PFE	RF before 2005	274,724	Non-PFE	725,276	274,724
PPF vs Non-PFE	PPF before 2005	115,504	Non-PFE	884,496	115,504
PA vs Non-PFE	PA before 2005	91,663	Non-PFE	908,337	77,873
Spill-over	Non-PFE near PFE, within 5 km buffer	292,078	Non-PFE beyond 5 km buffer	707,922	273,989

5. Results

5.1 Deforestation from 2006 to 2017 before propensity score matching

Table 2 represents deforestation calculated from GFCD in the PFE as a whole and land-use zones of PFE such as RF, PPF and PA established in and before 2005, and non-PFE. From 2006 to 2017, there was about 24,389 km^2 of deforestation, which represented about 6.58% of total forest area in 2005. Deforestation from 2006 to 2017 in the PFE as a whole and non-PFE was about 5,764 km^2 and 18,625 km^2, respectively, representing 4.12% and 8.08% of the respective forest areas in 2005. Among the land-use zones of PFE, we found that RF had the highest deforestation and PA was the lowest deforested land-use zoning. Deforestation in each land-use zoning of PFE was 4.77% in RF, 4.43% in PPF and 1.19% in PA. Before using matching, the PFE as a whole had a 3.95% lower deforestation than non-PFE, and RF, PPF and PA can avoid about 3.31%, 3.65% and 6.89% deforestation than non-PFE, respectively.

Table 2. Deforestation from 2006 to 2017

	Total area (km^2)	Forest area in 2005 (km^2)	Forest area in 2017 (km^2)	Deforestation (2006 – 2017)	
				Area (km^2)	(%)
PFE as a whole established in or before 2005	174,033	139,822	134,058	5,764	4.12
Non-PFE	439,830	230,621	211,997	18,624	8.08
RF before 2005	111,773	87,493	83,320	4,173	4.77
PPF before 2005	35,406	29,869	28,546	1,323	4.43
PA before 2005	26,854	22,459	22,191	268	1.19

5.2 Effectiveness of PFEs and land-use zones of PFE after propensity score matching

Covariates and propensity scores of PFE as a whole and non-PFE before and after PSM were shown in Supplementary materials. Before matching, PFEs were in flat land such as lower elevations and gentler slopes than non-PFE. PFEs were also located in the closer distance to the nearest railway and river than non-PFE, and in the further distance to roads and town. For each land-use zone of PFE, covariates for PA showed that PA was in the areas of higher elevation and deeper slope than non-PFE. Distance to the nearest town, the nearest railway and the nearest road for PA were greater and the distance to the nearest river and population density were lower than non-PFE. Covariates for RF and PPF showed similar trends to those of the PFE as a whole. However, distance to the nearest road for RF was lower than that for non-PFE, and PPF was in lower population density areas than non-PFE. The PSM improved the covariate balance of the whole PFE and each land-use zone of PFE (RF, PPF and PA) because the difference in mean values of covariates tended towards zero after PSM (shown in supplementary materials).

The ATT between PFE as a whole and non-PFE showed a statistically significant negative value, and the avoided deforestation from PFE was about 3.76% compared with non-PFE. Similarly, ATTs of each land-use zone of PFE were also negative values and the avoided deforestation percentages were 5.42% in PA, 3.63% in RF and 3.42% in PPF, respectively (Table 3). The result of spill-over analysis revealed that non-PFE within 5 km from the PFE had a significantly lower deforestation than non-PFE beyond 5 km from PFE.

Table 3. Average treatment effect on treated (ATT) for deforestation

	ATT				
	PFE	**RF**	**PPF**	**PA**	**Spill-over**
Estimate	-0.0376 ***	-0.0363***	-0.0342***	-0.0542***	-0.0144***
Standard error	0.0005	0.0006	0.0009	0.0009	0.0007

Notes: *** indicate $p < 0.001$

The annual deforestation rates in the PFE and non-PFE from 2006 to 2017 before and after matching are shown in Figure 3.2. After PSM, annual deforestation rate for non-PFE was approximately 1.5 times higher than that for PFE in 2006. Non-PFE maintained a higher annual deforestation rate than PFE from 2006 to 2017, both before and after PSM. Both PFE and non-PFE showed an increase of annual deforestation, but the non-PFE showed a more aggressive increase than PFE. The annual deforestation rate of non-PFE was approximately 2.3 times higher than that of forest in 2017 after PSM. Similarly, annual deforestation in RF and PPF showed increasing trends while the increases were lower than non- PFE. Annual deforestation in PA showed different trend from the non-PFE, RF and PPF, and PA have a little change in deforestation rates over time.

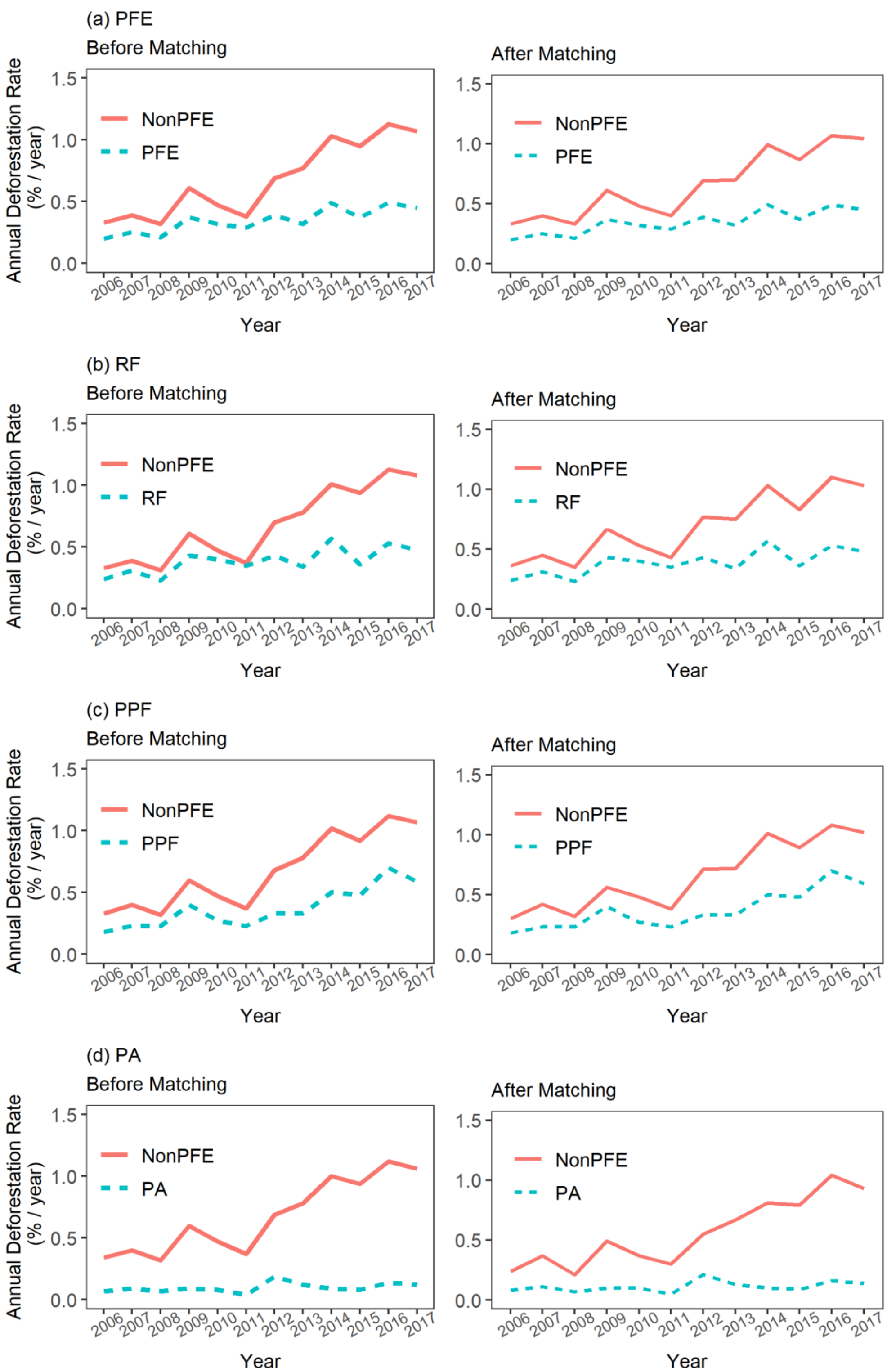

Figure.2. Annual deforestation rate between PFE and non-PFE before and after matching

6. Discussion

Evaluating the effectiveness of land-use zones is crucial to understand their performance in achieving their conservation goals. Here, we investigated the effectiveness of PFE and three land-use zones of PFE on reducing deforestation at the country-scale by controlling for land characteristics. The results clearly showed that PFE was effective in reducing deforestation by 3.76% compared to non-PFE. The results were similar to the case study in Cameroon (Bruggeman et al., 2015). In Myanmar, according to Vacant, Fallow and Virgin Land Management (VFVLM) Law (2012), there is a complex land management system in non-PFE, though forests in non-PFE could be managed by the Forest Department according to Forest Law (1992, revised in 2018). Thus, forests in non-PFE might be facing deforestation not only because of illegal logging but also due to the attempts to meet the targets of different government sectors such as agricultural expansion, mining, hydropower development and infrastructure development (Lim et al., 2017).

In addition to the forest conservation effectiveness of PFE, this study also showed that the PFE decreased deforestation in forests around the PFE. The result implies that the PFE in Myanmar does not lead to leakage of deforestation. One possible reason why the PFE did not lead to leakage may be related to standard operational procedure for the constitution of PFE. According to the standard operational procedures of constitution of PFE, forest settlement officers are responsible for inquiring and determining the rights of the people who are affected on the proposed PFE. Thus, the people can continue farming activities in their farmlands for a 30-year period. In addition, within RF and PPF, the extraction of forest products is allowed for self-consumption within a stipulated amount, but extraction for commercial use is not allowed. Because of these reasons, local people do not need to shift to non-PFE to clear and use the forests. However, although these reasons may explain the lack of leakage around the PFE, they do not fully explain why there is decreased deforestation around the PFE. The reduced deforestation around the PFE may be because of patrols. Forest department officers usually patrol within the PFE, but they sometimes also patrol in non-PFE. The presence of the officers and patrol efforts in non-PFE close to PFE may reduce forest clearing in those areas.

Among the land-use zones in the PFE, PA showed the highest avoided deforestation rates while comparing with non-PFE. Previous studies around the world have indicated PAs are effective for forest conservation (Agarwal et al., 2016; Andam et al., 2008; Bowker et al., 2017; Miranda et al., 2016). Thus, this result is not surprising at a global level. Previous studies in Myanmar have also shown the forest conservation effectiveness of PA (Connette et al., 2017; Htun et al., 2010; Liu et al., 2015; Songer et al., 2009), but these studies have simply compared PA and non-PA. This study confirmed that PAs in Myanmar were still effective for forest conservation after minimizing the effect of confounding variables.

This study showed that production forests in Myanmar (i.e., RF and PPF) reduced deforestation compared to non-PFE. Research in Cameroon (Bruggeman et al., 2015) and Bhutan (Bruggeman et al., 2018) has shown that land-use zoning for timber production was effective for forest conservation, but another study in Laos (Kukkonen & Tammi, 2019) found that production forests increased deforestation. Because research focusing on the forest conservation effectiveness of production forests is still limited, it is unclear whether there are common points that lead to success or failure of forest conservation in production forests between countries. In the case of Myanmar, one major factor that may help explain forest conservation effectiveness may be the timber extraction system in production forests. In Myanmar, since 1856, timber extraction in production forests has been conducted based on the MSS. Under the MSS, economically important trees larger than a predefined minimum size are selectively felled with a 30-year felling cycle (Win et al. 2018a). The number of felling trees does not exceed the Annual Allowable Cut (AAC), which is determined in each district and varies depending on the composition of trees across the districts. In addition to AAC, disturbance due to skidding is quite low under MSS, because MSS tends to use elephants rather than heavy machinery for skidding (Khai et al., 2016). From these reasons, a previous study in Myanmar also confirmed that logging is not related with deforestation (Mon et al., 2012). Thus, timber extraction in production forests may not cause deforestation. It is also worth noting that there is a less difference between RF and PPF. It might be related with the similar law-enforced status in RF and PPF. Based on their purposes, both RF and PPF might encounter forest cover loss due to extraction of timber including illegal logging and other forest products.

The results from this study support the need for policy and decision makers or conservationists from the forestry sector to consider the extension of PFE in other forests (i.e. forests in non-PFE) for forest conservation. According to Myanmar Forest Policy (1995), it is mandatory for RF and PPF to cover at least 30% and for PA to cover 5% of the country area. As a policy target and a commitment to UNFCCC from the forestry sector, the Myanmar government plans to expand the extent of PFE such as RF, PPF and PA to cover up to 40% of the country by 2030. Among PFE, production forests such as RF and PPF are targeted to increase to 30% of country's total area and the extent of PA is targeted to increase to 10%. As of August 2019, approximately 25.46% of the total land area was constituted as production forest. Approximately 5.85% of total land area was allocated as PA. Thus, the areas of production forest and PA will be expanded by 4.54% and 4.15% of total land area by 2030. Because this study showed that both production forest and PA reduce deforestation, and showed that around the PFE, there is no negative spill-over effect, the intention to extend PFE would be a good mechanism to control deforestation in Myanmar. While constituting PFE, it is vital to take into account both forest conservation and the needs of local communities who are living near or in the forests because they heavily rely on forest resources for their livelihoods, and participatory forest management is an important way to achieve sustainable forest management (Santika et al., 2019). For example, creating ecotourism sites within PA might be fruitful for Myanmar's economy and environmental conservation; on the other hand, there might be job opportunities and income generation for local communities. Thus, extension of the PFE may be an efficient way to achieve forest conservation as well as enhance local livelihoods.

However, it should be noted that both PFE, especially in production forests (both RF and PPF), and non-PFE showed an increasing trend of annual deforestation from 2006 to 2017. It is unclear why both non-PFE and production forests showed this increasing trend. Though lands in production forests and non-PFE are under the management of different ministries, one possible reason causing the increasing trend of deforestation might be agriculture expansion (Enters, 2017). With an increasing human population and land-tenure insecurity, agriculture expansion is becoming the significant driver of deforestation (Prescott et al., 2017). The deforestation due to agricultural expansion happens both in PFE and non-PFE (Enters, 2017).

We also suggested that perhaps the difference in the forest conservation effectiveness between production forests and PA is increasing because of stable deforestation in PA and increasing deforestation in production forests within the study period. Thus, the expansion of production forests may not make a significant contribution to forest conservation if the trend of increasing annual deforestation continues. Further efforts to mitigate the increase of deforestation in production forest (e.g. patrols, formulation of stronger rules and policies) should be conducted in parallel with the expansion of production forests. In addition, efforts to reduce deforestation in non-PFE should be made. This is because considerable areas of forests would be remained as non-PFE even if the PFEs expand to 40%. Forests in non-PFEs have the potential to be allocated to land uses other than forests, such as agriculture. Minimizing the impact due to land use reallocation should be considered.

It should be also noted that this study did not evaluate the difference of conservation effectiveness with different administrative district, because this is out of the scope of this study. In additions to PFE and non-PFE, administrative district may affect the degree of deforestation. For example, insecurity district due to civil war may be more susceptible to deforestation due to the difficulty in law enforcement. The study that evaluates conservation effectiveness of different administrative district may provide further evidence to reduce deforestation.

7. Conclusion

In Myanmar, PFE is constituted to fulfil different purposes for long-term maintenance of forest areas. It is categorized into RF, PPF and PA. Though many studies have evaluated forest cover changes in Myanmar, few have investigated the effectiveness of the land-use zone of PFE (especially PA) in reducing deforestation at the national scale. In this study, we evaluated the impacts of the PFE as a whole and of different land-use zones in the PFE such as RF, PPF and PA in reducing deforestation at national level compared with non-PFE using a matching method. The results showed that not only the PFE as a whole but also all the land-use zones of PFE avoided deforestation compared to non-PFE. Matching showed that the PFE in Myanmar was effective in reducing deforestation due to protection and not due to land characteristics. However, the PFE and non-PFE showed an increasing trend of annual deforestation between 2006 and 2017. Thus, further efforts to mitigate deforestation in production forest should be conducted. In addition, ways to reduce deforestation in non-PFE should be investigated.

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Supplementary Materials

Table S1: Covariate Balance before and after propensity score matching using PFE as a whole as treatment and non-PFE as control

	Before Matching			**After Matching**		
	Means Treated (n=375474)	**Means Control (n=624526)**	**Mean Difference**	**Means Treated (n=375474)**	**Means Control (n=375474)**	**Mean Difference**
Elevation (m)	573.96	748.47	-174.51	573.96	579.72	-5.76
Slope (˚)	16.20	17.45	-1.25	16.20	16.33	-0.13
Distance to nearest Town (m)	27011.40	22994.99	4016.41	27011.40	25959.20	1052.20
Distance to nearest Railway (m)	87194.40	100730.38	-13535.98	87194.40	88818.30	-1623.90
Distance to nearest Road (m)	12783.06	12250.84	532.22	12783.06	12712.99	70.07
Distance to nearest river (m)	28297.54	35366.67	-7069.13	28297.54	27920.94	376.60
Population density (per km^2)	40.88	34.60	6.28	40.88	39.50	1.38

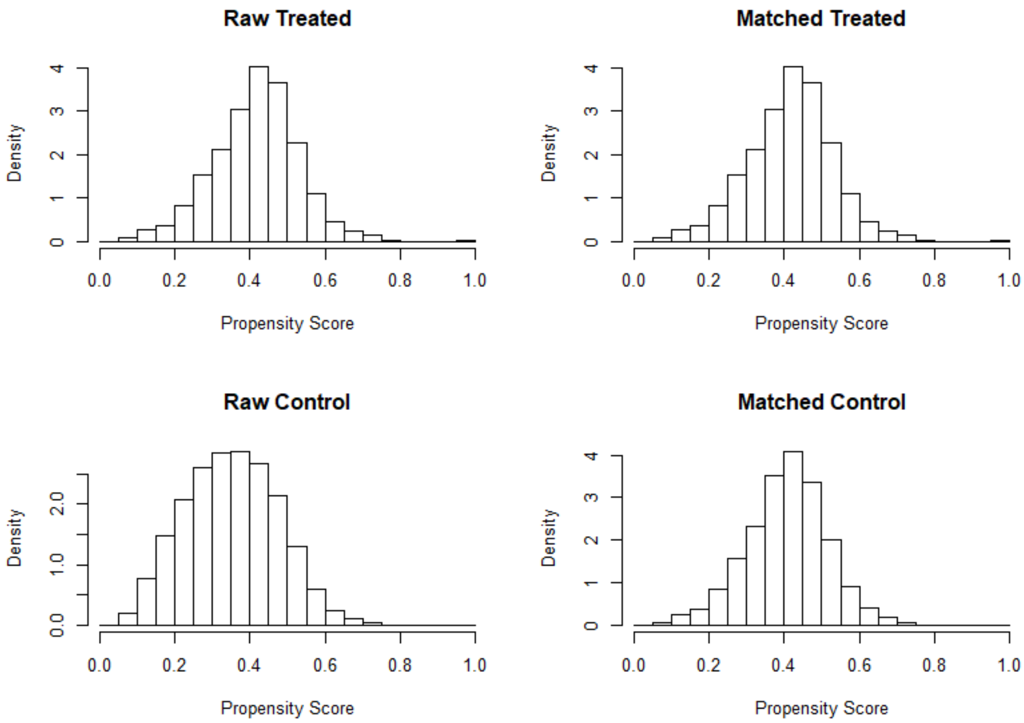

Figure S1: Propensity Score before and after matching using PFE as a whole as treatment and non- PFE as control

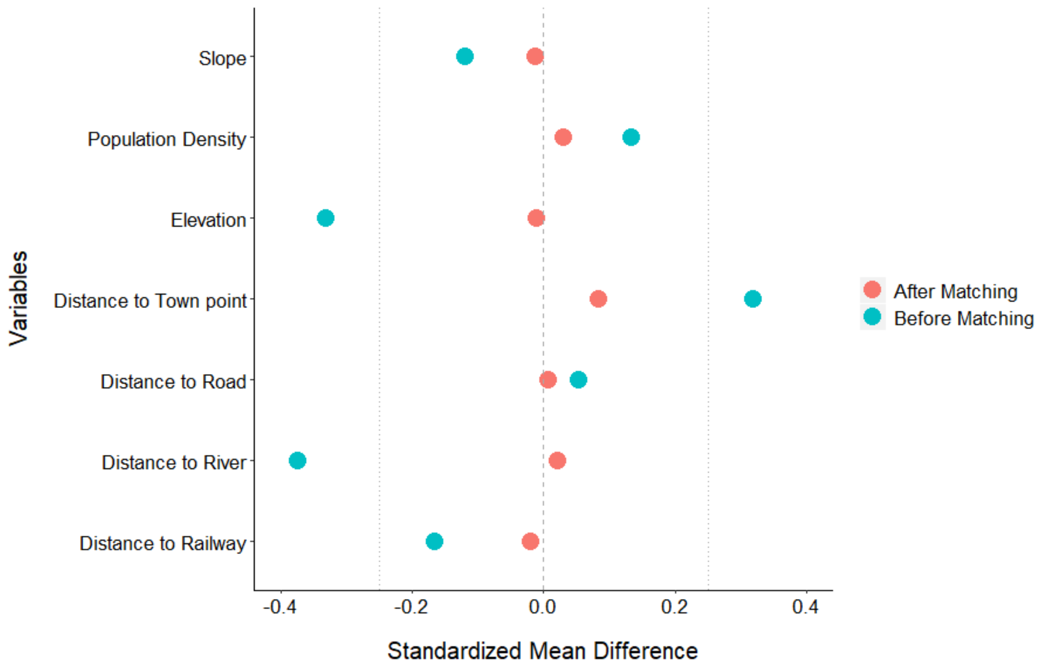

Figure S2: Covariate balances before and after matching using PFE as a whole as treatment and non- PFE as control

Table S2: Covariate Balance before and after propensity score matching using PA as treatment and non- PFE as control

	Before Matching			**After Matching**		
	Means Treated (n=91663)	**Means Control (n=908337)**	**Mean Difference**	**Means Treated (n=77873)**	**Means Control (n=77873)**	**Mean Difference**
Elevation (m)	979.48	749.33	230.15	836.39	870.92	-34.53
Slope (˚)	20.95	17.44	3.51	19.30	19.76	-0.46
Distance to nearest Town (m)	34937.24	22977.09	11960.15	31766.70	32472.93	-706.23
Distance to nearest Railway (m)	130731.71	100819.18	29912.53	121940.01	117600.52	4339.49
Distance to nearest Road (m)	20998.05	12274.22	8723.84	17668.65	18561.74	-893.09
Distance to nearest river (m)	32340.04	35390.24	-3050.20	32497.88	32577.30	-79.42
Population density (per km^2)	15.36	34.61	17.08	17.32	20.02	4.50

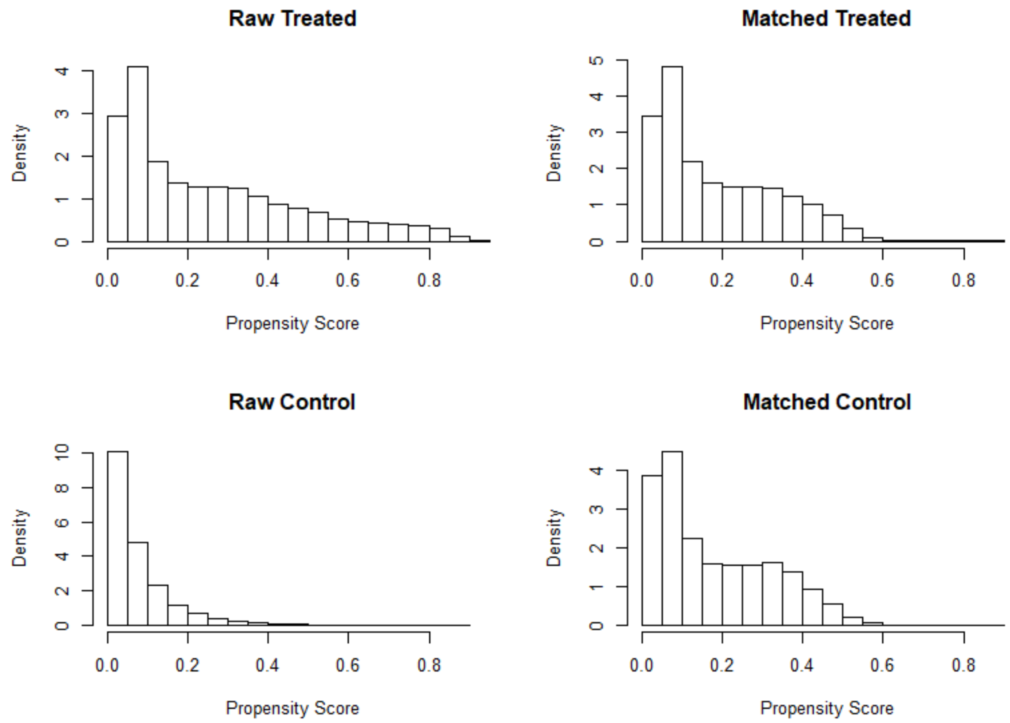

Figure S3: Propensity score before and after matching using PA as treatment and non-PFE as control

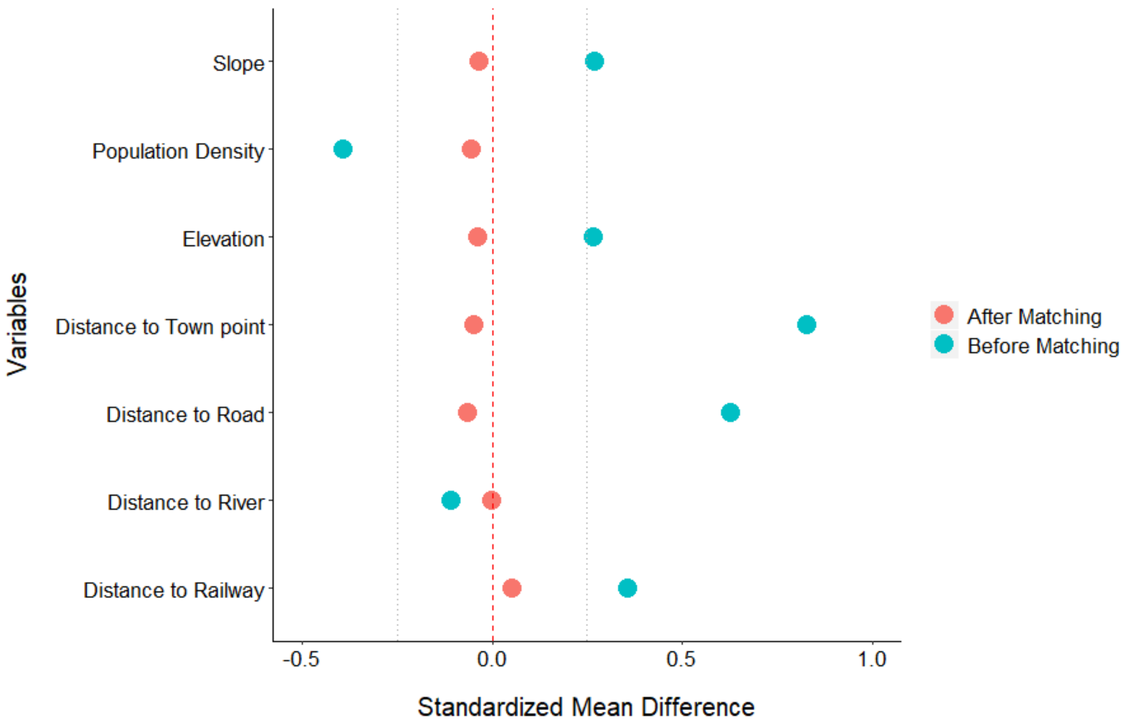

Figure S4: Covariate balances before and after matching using PA as treatment and non- PFE as control

Table S3: Covariate Balance before and after propensity score matching using RF as treatment and non- PFE as control

	Before Matching			**After Matching**		
	Means Treated (n=274724)	**Means Control (n=725276)**	**Mean Difference**	**Means Treated (n=274724)**	**Means Control (n=274724)**	**Mean Difference**
Elevation (m)	462.13	750.02	-287.89	462.13	455.23	6.90
Slope (˚)	14.84	17.45	-2.61	14.84	14.86	-0.02
Distance to nearest Town (m)	26314.11	23006.03	3308.08	26314.11	25673.78	640.33
Distance to nearest Railway (m)	74049.65	100907.79	-26858.13	74049.65	76863.04	-2813.39
Distance to nearest Road (m)	10742.98	12300.05	-1557.07	10742.98	10746.84	-3.86
Distance to nearest river (m)	27918.48	35419.47	-7500.99	27918.48	26836.06	1082.42
Population density (per km^2)	50.78	34.68	16.10	50.78	45.38	5.40

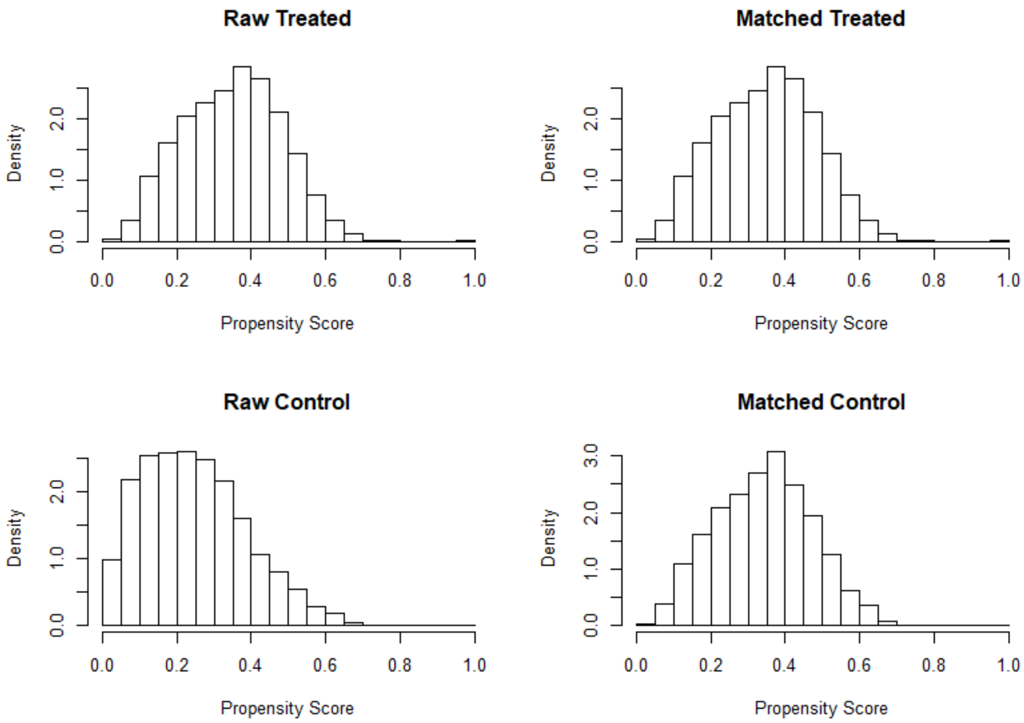

Figure S5: Propensity Score before and after matching using RF as treatment and non-PFE as control

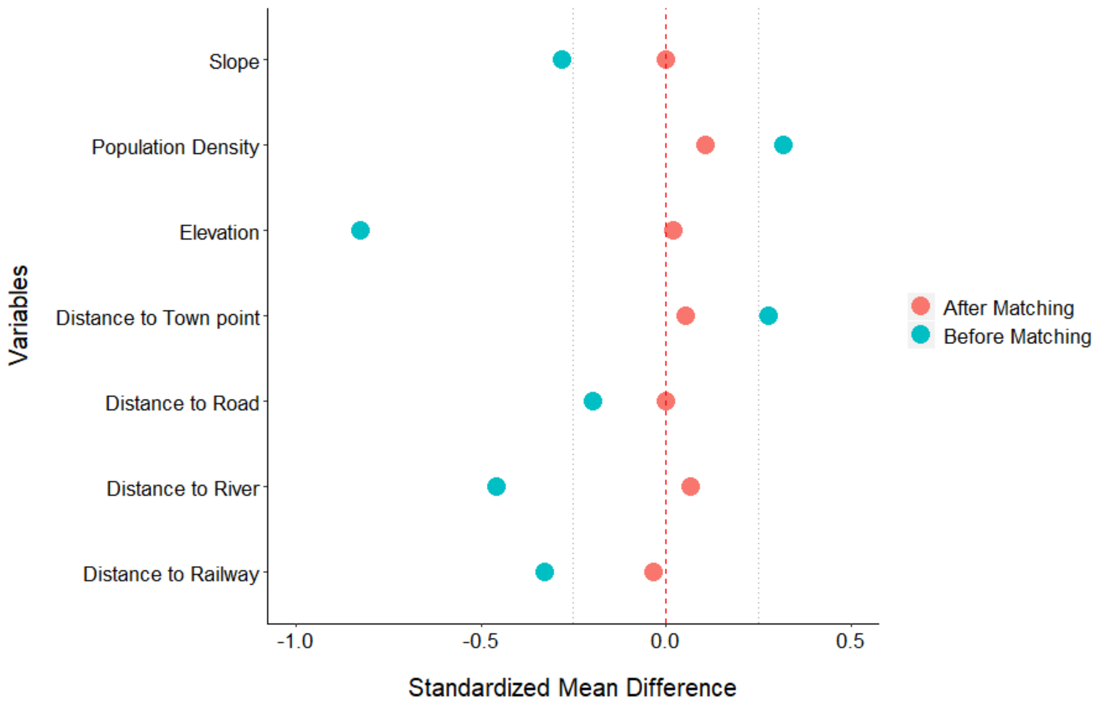

Figure S6: Covariate balance before and after matching using RF as a treatment and non- PFE as control

Table S4: Covariate Balance before and after propensity score matching using PPF as treatment and non- PFE as control

	Before Matching			**After Matching**		
	Means Treated (n=115504)	**Means Control (n=884496)**	**Mean Difference**	**Means Treated (n=115504)**	**Means Control (n=115504)**	**Mean Difference**
Elevation (m)	583.90	749.37	-165.47	583.90	585.23	-1.33
Slope (˚)	16.56	17.45	-0.89	16.56	16.53	0.03
Distance to nearest Town (m)	23243.50	23005.61	237.89	23243.50	23453.67	-210.17
Distance to nearest Railway (m)	87076.21	100817.71	-13741.50	87076.21	86636.84	439.37
Distance to nearest Road (m)	12367.70	12282.77	84.93	12367.70	12313.83	53.87
Distance to nearest river (m)	26377.63	35430.26	-9052.63	26377.63	26386.10	-8.47
Population density (per km^2)	30.48	34.68	-4.20	30.48	31.40	-0.92

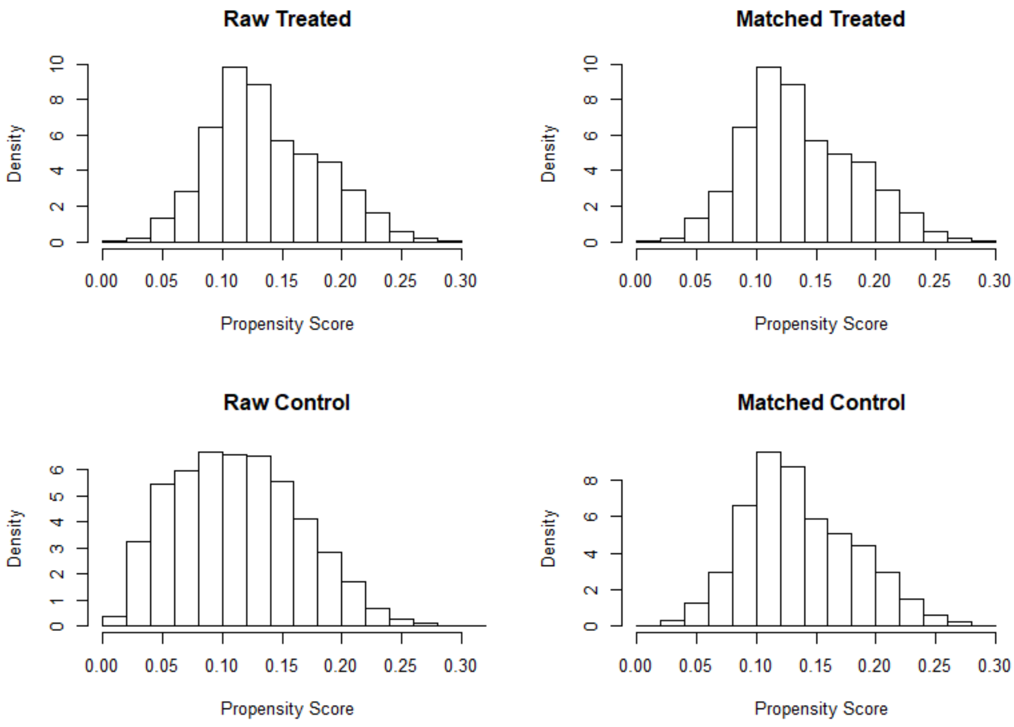

Figure S7: Propensity Score before and after matching using PPF as treatment and non- PFE as control

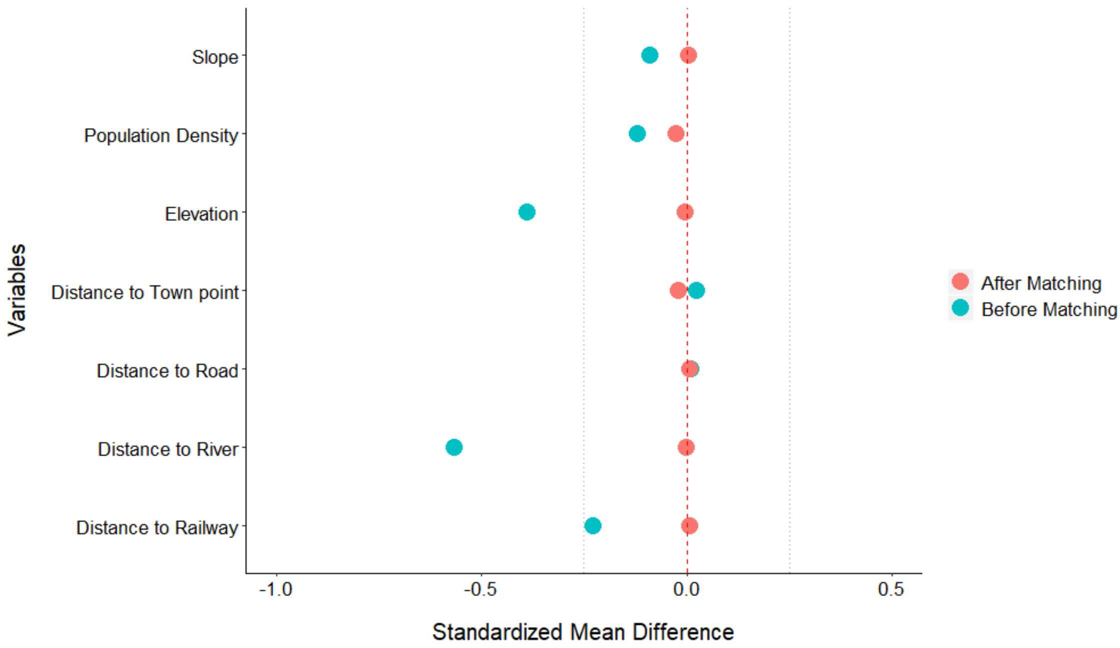

Figure S8: Covariate balance before and after matching using PPF as treatment and non- PFE as control

Table S5: Covariate Balance before and after propensity score matching using non- PFE within 5 km buffer as treatment and other remaining non- PFE to check spillover

	Before Matching			**After Matching**		
	Means Treated (n=292078)	**Means Control (n=707922)**	**Mean Difference**	**Means Treated (n=273989)**	**Means Control (n=273989)**	**Mean Difference**
Elevation (m)	509.41	848.82	-339.41	532.25	552.86	-20.61
Slope (˚)	14.69	18.58	-3.89	14.98	15.18	-0.20
Distance to nearest Town (m)	21742.84	23510.88	-1768.04	21823.61	22125.53	-301.92
Distance to nearest Railway (m)	74611.40	111622.10	-37010.70	77479.71	82691.11	-5211.40
Distance to nearest Road (m)	8777.88	13707.38	-4929.50	9079.01	9238.28	-159.27
Distance to nearest river (m)	27123.30	38866.10	-11742.80	27752.44	28132.05	-379.61
Population density (per km^2)	45.85	30.02	15.83	44.40	39.80	4.60

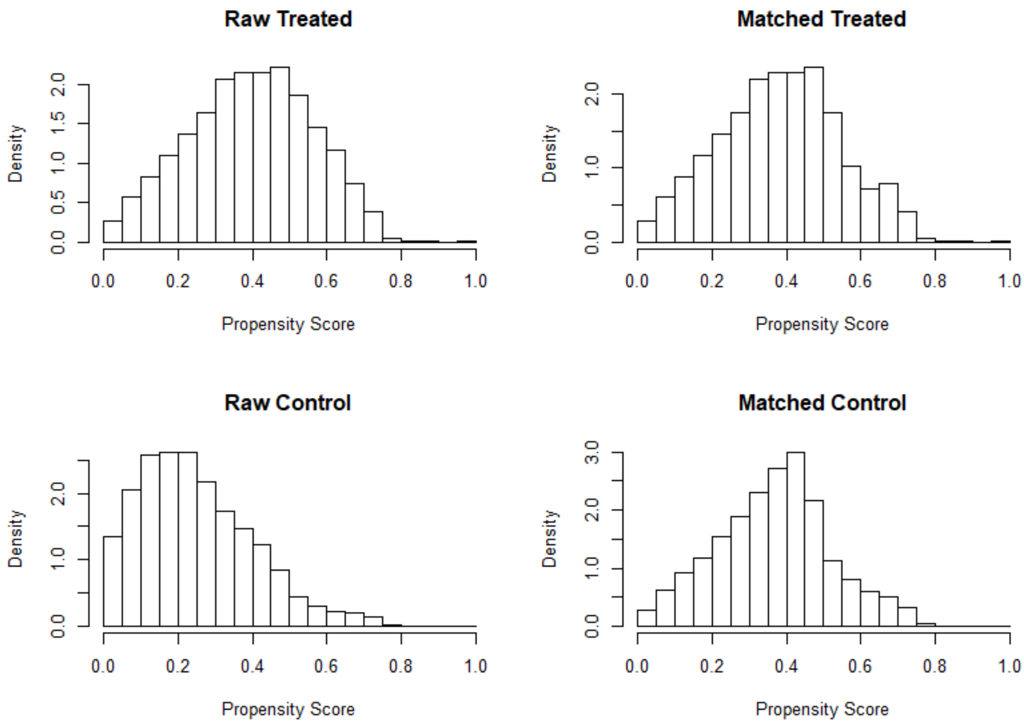

Figure S9: Propensity Score before and after matching using non- PFE within 5 km buffer as treatment and other remaining non-PFE as control

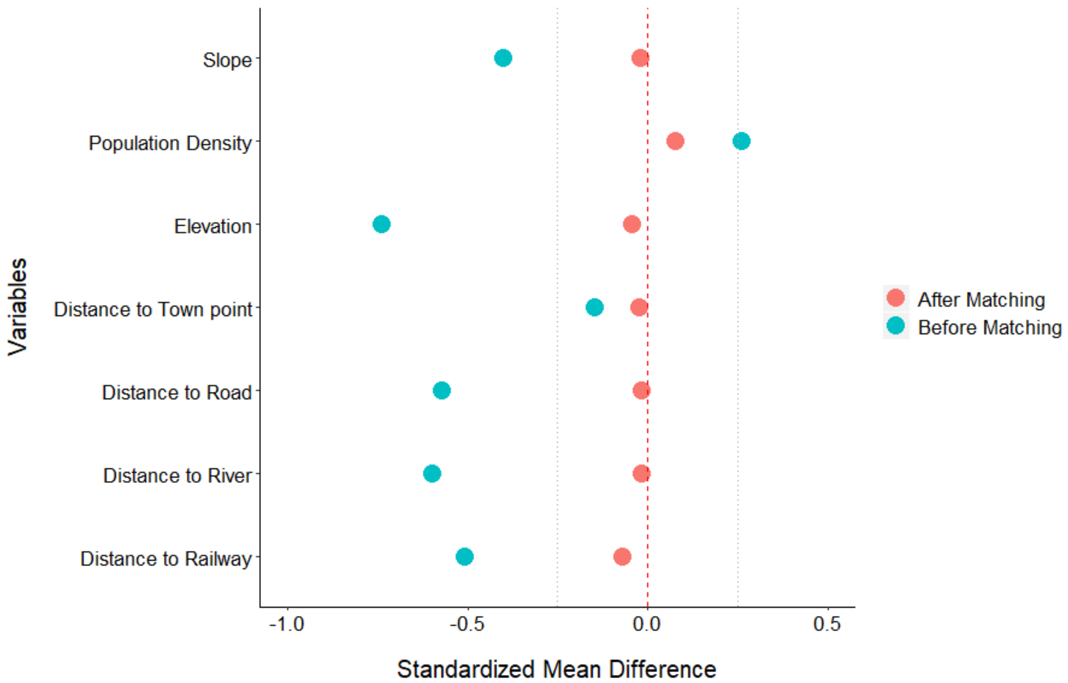

Figure S10: Covariate balance before and after matching using non-PFE within 5 km buffer as treatment and other remaining non-PFE as control