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Resource Collection Polygons: A spatial analysis of woodfuel collection patterns☆

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Introduction

Woodfuels represent only about 9% of global primary energy consumption, but constitute more than 50% of the global wood harvest (FAO, 2013, 2016b; REN21, 2018).[1] However, this extraction of wood is not equally distributed globally, and can constitute almost 90% of all wood removals in some countries, such as those in Sub-Saharan Africa (FAO, 2010), making it one of the leading forest products. In the case of developing economies, this is driven by the roughly 2.6 billion individuals (almost 40% of the world's population) dependent on solid fuels (including traditional biomass such as wood, crop residue, and dung) to meet their daily household cooking energy requirements (Arnold, Kohlin, Persson, & Shepherd, 2003; IEA, 2016; World Bank & IEA, 2017).[2] Forests provide an important benefit to both the formal and informal economy, and help alleviate the need for many low-income households to purchase needed energy inputs. In many developing countries, the share of woodfuels in total household forest income can account for almost 35% of forest income and make up to 8% of total household income (Angelsen et al., 2014; Vedeld, Angelsen, Bojö, Sjaastad, & Kobugabe Berg, 2007). Physically, woodfuels contribute 50 to 90% of all household energy, and 60 to 80% of total wood consumption (FAO, 2016a). Even though most of this extraction happens outside the formal economy for self-consumption, in 2016, global woodfuel exports and imports generated over US $850 million (FAO, 2016a). The formal woodfuel industry also impacts urban-rural monetary flows, especially in Africa, where charcoal is produced in rural areas but consumed in urban areas (Chidumayo & Gumbo, 2013). In coming years, due to climate change, rising fossil fuel prices, and persistent poverty, the importance of woodfuels in the formal market for industrial purposes is likely to increase even further as the world strives towards a low carbon economy, while demand for household purposes is likely to remain static (IEA, 2017). Thus, it is becoming essential to manage our natural resources sustainably to alleviate the negative climatic, social, and economic impacts that might arise. However, to efficiently and sustainably manage woodfuel extraction, we require a deeper understanding of woodfuel demand and supply, in particular, the knowledge of what is extracted, how much is extracted, and where it is extracted from.

There is growing empirical research on woodfuel demand linking socio-economic and demographic factors to woodfuel consumption (Berrueta, Edwards, & Masera, 2008; Bhatt, Negi, & Todaria, 1994; Granderson, Sandhu, Vasquez, & Ramirez, 2009; Kituyi, Marufu, Huber, & Wandiga, 2001; Kumar & Sharma, 2009; Singh, Rawat, & Verma, 2010), and on determining local consumption differences based on geographical region, altitude, and local cooking habits (Bhatt et al., 1994; Kumar & Sharma, 2009; Pattanayak, Sills, & Kramer, 2004). However, research on woodfuel collection behavior is limited, specially relating to spatial and geographical measures (Bailis, Berrueta, Chengappa, & Dutta, 2007). Those who have studied woodfuel collection have set the research in household frameworks that rely on self-reported data (Top, Mizoue, Kai, & Nakao, 2004), or large scale analysis to map regional and national patterns (Robert Bailis, Drigo, Ghilardi, & Masera, 2015; Jagger & Perez-Heydrich, 2016). While these can each be informative, to fully understand woodfuel extraction patterns we require multi-scale spatially explicit estimates (such as collection area, distance from village, and accessibility). At the local level it is necessary to go beyond simple circular buffers around villages and understand heterogeneity in local woodfuel collection locations (Masera et al., 2006). It is also imperative to understand the factors

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[1] Woodfuels refer to all use of woody biomass for energy generation, including direct use of wood as well as processed wood in the form of pellets or charcoal. Fuelwood refers specifically to woody biomass used directly for energy in simple combustion systems (primarily cookstoves).

[2] In industrialized economies the wood extracted for energy purposes is used in significantly more efficient systems, generally for heating purposes or electricity generation. For the purposes of this paper, we focus solely on wood extracted for household cooking and heating needs in simple household systems prevalent in low-income countries.

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that drive these spatial patterns such as socio-demographics, local laws, and culture. Therefore, to fill this gap in understanding woodfuel collection behavior, we answer the following research questions:

1. What are the geographical and spatial patterns to household fuelwood[3] collection in rural India?
2. How do the fuelwood collection patterns (i.e. location and distance) differ between and within regions?
3. What key variables drive the differences in fuelwood collection patterns?

To answer these questions we pilot a novel application of Home Range Analysis, a method for understanding the movement patterns of wildlife. Applying this method we construct what we have termed Resource Collection Polygons (RCPs) to evaluate household woodfuel collection patterns. To the best of our knowledge, this is the first time that home range analysis has been applied to analyze human behavior, such as woodfuel collection patterns and boundaries. The further development and application of this method could have significant implications for resource management in this region and other parts of the developing world that rely heavily on woodfuels. It can serve as a base to build upon for further, more detailed analysis, such as using kernel density method to understand frequency and intensity of woodfuel extraction. It can also be applied to understand other human spatial patterns, such as water collection or food foraging around villages.

A brief history of woodfuel research

The early 1970's saw a surge of interest on woodfuels, and a rise in the belief of a worldwide woodfuel crisis leading to widespread deforestation (Agarwal, 1986; Eckholm, Foley, Barnard, & Timberlake, 1984). This belief was driven by a sharp rise in fossil fuel prices (due to the energy crisis), and various publications (such as Eckholm et al., 1984), suggesting a major woodfuel crisis in the coming decades as a result of a major supply/demand gap. Higher efficiency cookstoves, requiring lesser quantities or no use of woodfuel, were seen as a solution, and various governments (e.g. China, India) started large scale intervention programs. However, by the late 1980's the woodfuel shortage did not seem to be as calamitous as earlier suggested (Arnold et al., 2003; Cecelski, 1984), and its harvesting was no longer considered the primary source of global deforestation. Questions were raised about the assumption that foraging of fuelwood by the rural poor was the main cause of shortage (Agarwal, 1986; Arnold et al., 2003; McGranahan, 1991). Instead, new research indicated that clearing of land for agriculture (as a result of low agricultural productivity and population growth) was the greatest driver of permanent removal of tree cover (World Bank, 2013). Research also indicated that while there were areas of concern, or so-called hot-spots, it was not a widespread global issue. In fact, most woodfuel supply was not globally unsustainable nor an environmental threat since a large proportion of the rural supply came from dead trees, trees outside forests (e.g. farms), and farm residue. However, there were concerns that a concentrated demand in absence of regulations could contribute to degradation and deforestation (mainly from charcoal production), which would directly affect local communities, as forest ecosystems are their main source of income and livelihood (Byron & Arnold, 1999; Salafsky, 1994; Smith & Scherr, 2003). As a result, more efficient cookstoves continue to be promoted to reduce negative impacts on forest resources from reduced use of woodfuels and climate change from the resulting reduction in emissions (Singh, Pachauri, & Zerriffi, 2017).

This focus on woodfuel consumption for over three decades helped create a vast literature base on the socio-economics of woodfuel demand, variables affecting the quantity of woodfuels consumed, and the variation in global woodfuel consumption and collection patterns. For example, labor energy expenditure is highest in temperate regions for fuelwood collection in the Garhwal Himalayas but the consumption is highest in tropical regions, with considerable oscillation in consumption rate across seasons (Kumar & Sharma, 2009). Looking beyond the household level, we notice that woodfuel consumption depends largely on availability and differs between catering enterprises, public institutions (e.g. schools, colleges), and households, and also between urban and rural regions (Kituyi et al., 2001). Furthermore, income induced substitutions tend to move in the direction of income change whereas substitutions induced due to scarcity move towards less sophisticated fuels. Application of unique methods to rural households in Indonesia, such as travel cost models, find that dependence on forests could be reduced through increasing forest access costs, park staff activity, trees on farm, use of alternative fuels, improved cooking technologies, and overall development and generation of wealth (Pattanayak et al., 2004).

While an established and still-growing literature exists on the demand side factors and the role of woodfuels in households, there is limited research on supply side geographical and spatial extents to understand woodfuel collection patterns (Masera, Bailis, Drigo, Ghilardi, & Ruiz-Mercado, 2015; Bailis et al., 2007). A few researchers have examined the spatial aspects of woodfuel collection and consumption, but they were limited in geographical scale and used large zones near the study sites (i.e. uniform circular buffers of given radii). For example, Top et al. (2004, 2006) studied fuelwood consumption patterns in Cambodia at three different scales (1, 3 and 5 km radii) in the Kampong Thom Province and found that high population density was linked to lower forest resource availability. Similarly, in Malawi, degraded forest resources led to woodfuel consumption supported by other means such as purchasing of fuelwood or charcoal thus increasing fuel expenditures (Jagger & Perez-Heydrich, 2016). In Uganda, however, biomass reduction due to degraded forests increased the use of low quality fuel and crop residues by households (Jagger & Kittner, 2017).

Models such as WISDOM and Mofuss have been created to better understand global woodfuel supply. WISDOM (Woodfuel Integrated Supply/Demand Overview Mapping), a GIS based spatially explicit model, uses administrative or regional scales, from satellite images and national datasets, to identify woodfuel priority areas or hot spots across countries (Ghilardi, Guerrero, & Masera, 2007; Masera et al., 2006). It adds rich information to spatial woodfuel supply by identifying global hot spots indicating regions where woodfuel is non-renewably sourced (Bailis et al., 2015), and has been applied to multiple countries, including Mexico, Nepal, Slovenia, Senegal, and East Africa (Drigo, 2004a, 2004b, 2005, 2017). However, WISDOM is limited to larger scale analyses (even if there is higher resolution satellite data, it needs to be scaled to regional publicly available data) and lacks information at lower community level spatial scales. Mofuss (Modeling Fuelwood Savings Scenarios), another GIS tool, developed to quantify non-renewable woodfuel extraction, builds upon the WISDOM model (Ghilardi et al., 2016). It is capable of incorporating uncertainties for data-poor landscapes, savings from reduced woodfuel consumption, and projects scenarios for the future (Ghilardi, Tarter, & Bailis, 2018). However, even though it includes socio-economic inputs, it does not look at specific local heterogeneity.

Thus, on the one hand, there is literature that is highly local but has simplified woodfuel collection to be in a uniform radius around population centers (Jagger & Perez-Heydrich, 2016; Top et al., 2004). On the other hand there are attempts to measure forest impacts more extensively but at a non-local scale (Masera et al., 2006). What is missing is a method to understand local spatial patterns of woodfuel collection.

Home range

The concept of a “home range” first arose when Darwin (1861) noticed that animals restricted their movements to certain territories.

[3] When referring to woodfuel collection within our research sites, we include only fuelwood, as there is no charcoal collection in this region.