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ORIGINAL ARTICLE

Armed conflict distribution in global drylands through the lens of a typology of socio-ecological vulnerability

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Abstract Motivated by an inconclusive debate over implications of resource scarcity for violent conflict, and common reliance on national data and linear models, we investigate the relationship between socio-ecological vulnerability and armed conflict in global drylands on a subnational level. Our study emanates from a global typology of smallholder farmers' vulnerability to environmental and socioeconomic stresses in drylands. This typology is composed of eight typical value combinations of variables indicating environmental scarcities, resource overuse, and poverty-related factors in a widely subnational spatial resolution. We investigate the relationships between the spatial distribution of these combinations, or vulnerability profiles, and geocoded armed conflicts, and find that conflicts are heterogeneously distributed according to these profiles. Four profiles distributed across low- and middle-income countries comprise all drylands conflicts. Comparing models for conflict incidence using logit regression and receiver operator characteristic analysis based on (1) the set of all seven indicators as independent variables and (2) a single, only vulnerability profile-based variable proves that the nonlinear typology-based variable is the better explanans for conflict incidence. Inspection of the profiles' value combinations makes this understandable: A systematic explanation of conflict incidence and absence across all degrees of natural resource endowments is only reached through varying importance of poverty and resource overuse depending on the level of endowment. These are nonlinear interactions between the explaining variables. Conflict does not generally increase with resource scarcity or overuse. Comparison with conflict case studies showed both good agreement with our results and promise in expanding the set of indicators. Based on our findings and supporting literature, we argue that part of the debate over implications of resource scarcity for violent conflict in drylands may be resolved by acknowledging and accounting for nonlinear processes.

Keywords Socio-ecological system · Cluster analysis · Subnational resolution · Nonlinear · Resource scarcity · Environment

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Introduction

There is a long-standing debate on the role of natural resource factors in explaining violent conflict, spanning from the position that conflicts occur due to "supply induced" scarcity of resources, particularly renewable resources (Bächler 2000; Homer-Dixon and Blitt 1998; Homer-Dixon 1999) and the view that mainly the socio-economic/political context is decisive for generating violent conflicts (Brauch 2003; Diehl and Gleditsch 2001; de Soysa 2005).

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Continuing this contestation, the same inconclusive yet advancing debate is reflected in the recent surge of literature on in how far elements of a broadly defined climate variability can contribute to causing violent conflict by increasing resource scarcity (Scheffran et al. 2012; O'Loughlin et al. 2012; Buhaug et al. 2008). Some studies make causal associations with recent global scale climate variability (Hsiang et al. 2011), regional warming in sub-Saharan Africa (Burke et al. 2009), and observed rainfall deviations in Africa (Hendrix and Saleyhan 2012) to violent conflict, while other studies find no or only weak links (e.g., Buhaug 2010, Salehyan 2008) or, again, put emphasis on social context (e.g., Benjaminsen et al. 2012). Scheffran and Battaglini (2010) review regions and systems that may be particularly vulnerable to climate-change-induced resource scarcity. These links, contested or not, commonly are from or relate to drylands regions.

So far it seems clear that studies which particularly focused on a single indicator, such as water scarcity, as a source of conflict have generally not been able to find definitive evidence in support of the environmental scarcity arguments (Benjaminsen 2008; Meier et al. 2007; Wolf 1999).

Besides the question which variables are assumed to explain conflict occurrence, it is important how they are combined. For example, several statistical ("large-N") studies on violent conflict occurrence (e.g., Levy et al. 2005) rely on a comprehensive set of explaining variables (socioeconomic factors, resource scarcities, environmental factors, political factors, etc.) but commonly use linear models to combine them. This implies that the additional effect of variable B (e.g., a socioeconomic factor) on conflict probability is independent from the value of variable A (e.g., an environmental condition), which is a strong and restrictive hypothesis. One possible reason why the above-mentioned debate is still unresolved is that explaining variables' influences on conflict may depend on nonlinear combinations of their values: different relations might be valid under different conditions.

Another important reason is the spatial resolution of the explaining variables and the conflict data. A growing number of recent studies emphasize the need to use less aggregated, subnational data (Scheffran et al. 2012; Buhaug 2010; Burke et al. 2009; Raleigh et al. 2006). While this is facilitated by the increasing availability of geo-referenced databases of conflict locations for Africa (Hendrix and Salehyan 2012; Melander and Sundberg 2011; Raleigh et al. 2010), studies linking that data to subnational independent variables are still relatively sparse. The body of empirical research for investigating links between debated causes of conflict and the conflicts themselves largely applies country-level analyses, likely masking subnational variations (Blattman and Miguel 2010; Levy et al. 2005). While nationwide values for some socioeconomic and policy-related variables, such as for GDP/cap, may be adequate, this may be insufficient for bio-physical data and other socioeconomic and policy data.

Motivated by the observations above, this paper applies a typology of smallholder farmer vulnerability in global drylands from Kok et al. (2010, 2013) to empirically assess the possible connection between environmental conditions, poverty-related factors, and violent conflicts. The typology from Kok et al. (2010, 2013) resulted from clustering almost exclusively subnational, spatially explicit datasets of key biophysical, resource-related, and socioeconomic factors that were considered most important for generating drylands vulnerability and is thereby an intrinsically nonlinear approach. We investigate in how far these typical combinations of natural and socioeconomic factors which characterize the vulnerability of drylands population to global environmental change (Geist and Lambin 2004; Jäger and Kok 2007; Reynolds et al. 2007; Sietz et al. 2011) are also relevant for the spatial conflict distribution and conflict proneness of the respective socio-ecological system.

Besides this methodological innovation, such a study could generate some general conclusions about the drylands vulnerability–conflicts nexus. The applied drylands typology concentrates on socioeconomic and environmental factors where data with global coverage and widely subnational resolution were available. Next to these socioeconomic and environmental factors, the literature shows that political factors are also important for driving violent conflict (e.g., Buhaug 2010; Salehyan 2008; Lata 2003). These include, for example, political marginality (Raleigh 2010; Adano et al. 2012), inconsistency of political institutions (Hegre and Sambanis 2006; Gates et al. 2006), or political instability (Fearon and Laitin 2003).

Acknowledging this restriction with respect to political factors and in the case of significant relations between conflict occurrence and drylands vulnerability type, our approach will allow us nonetheless to contribute to the discourse on the role of environmental factors in conflict explanation by investigating whether there are (a) different typical combinations of values of socioeconomic and environmental factors with conflict incidence in drylands, (b) systematic relationships *between* these factors that explain conflict distribution and (non-)incidence, and (c) measurable advantages of this approach over commonly used linear fits. On the condition that these points apply, we can contribute to a better understanding of violent conflict incidence under drylands vulnerability and of the role of natural resources therein without denying the role of political factors. The latter would probably be responsible for the remaining unexplained variance in conflict occurrence.

Our paper is structured as follows: We provide the conceptual and methodological background for the typology of drylands vulnerability from Kok et al. (2010, 2013, Sect. "Methodology"). With this nonlinear research design, we investigate what the eight spatially explicit clusters constituting the socio-ecological typology of global drylands vulnerability tell us about the distribution of conflicts therein (Sect. "Conflict distribution"). Then, we ask in how far using this typology method compares to traditional linear methods of mono- and multivariate fits in terms of statistical explanatory power for this incidence or lack of conflicts (Sect. "Comparison with mono- and multivariate fits").

We then qualitatively systematize the combinations of socio-ecological and environmental factors to explain these results by linking their cluster-specific interpretations to conflicts incidence or peace in the light of socio-ecological vulnerability (Sect. "Linking conflict incidence to cluster interpretations"). We ground truth selected interpretations with literature on conflict causes in the Horn of Africa (Sect. "Ground truthing—exemplary conflict causes in the Horn of Africa and vulnerability profiles").

We then discuss with what varying importance socio-ecological and environmental factors best determine conflict proneness and peace in drylands, taking the lack of political factors into the equation (Sect. "Discussion", discussion). By doing so we, can conclude with what this contributes to explaining violent conflict, or peace, in the resource scarcity debate in view of a) a lack of generalizable statements in studies about the role of natural resource factors and b) predominantly nonlinear methodologies used for explanations (Sect. "Discussion", conclusions).

Methodology

Vulnerability-generating mechanism in drylands

Global drylands occupy 41 % of the Earth's land surface and are home to half of the world's population living in poverty (Dobie 2001). These regions are characterized by low rainfall and high rates of evaporation. The marginal resources available in fragile environments to base livelihoods on are subject to a tight human–nature interdependence (Safriel et al. 2005), resulting in a high risk of overexploitation.

We investigated the spatial distribution of violent conflicts in drylands on the basis of the drylands vulnerability typology from Kok et al. (2010, 2013). They introduce a formalized method for identifying general mechanisms creating vulnerability in different places in the world and apply it to drylands. In the following two sections, we summarize the vulnerability-generating mechanisms in drylands and the steps for devising this typology.

Earlier studies have identified key mechanisms in drylands influencing the vulnerability of farmers (Geist and Lambin 2004; Jäger and Kok 2007; Reynolds et al. 2007). In terms of the key components of these mechanisms, Reynolds et al. (2007) identify five key variables for the "Dryland Development Paradigm", comprising high variability in rainfall, low soil fertility, sparse populations, isolation (e.g., remoteness from markets), and distant voice and remote governance. Key characteristics identified as constituting a typology of vulnerability specifically for drylands farmers, and threatening human wellbeing (hereafter HWB), include the increasing pressures on natural resources from a growing population, limited and insecure access to water and fertile soils, and soil degradation resulting from overuse, combined with the breakdown of traditional coping mechanisms, and barriers to alternative livelihoods (Geist and Lambin 2004; Safriel et al. 2005; UNEP 2007; Sietz et al. 2011; Kok et al. 2013).

Kok et al. (2010, 2013) and Sietz et al. (2011) revisited these mechanisms, focusing on the most prevalent ones observed in case studies in drylands literature. These include the overuse of scarce natural resources resulting in their degradation (Dregne 2002), its negative feedback on agricultural production and income generation (e.g., Safriel and Adeel 2008), and the dependence of income generation on "soft and hard infrastructure" (e.g., Shiferaw et al. 2008) which also influences the improvement of agricultural techniques in conjunction with available capital (Thomas 2008; Twomlow et al., 1999). Sietz et al. (2011) provide thematic and spatial entry points to reducing vulnerability in such a typology of drylands vulnerability.

In order to quantitatively investigate drylands vulnerability, Kok et al. (2013) identified spatially explicit indicators with subnational resolution for the most important processes and elements of these mechanisms considering poverty, the conditions and use of natural resource, agro-constraints, population density, and isolation (see also Sietz et al. 2011). Providing the basis for the typology in this study, Kok et al. (2010, 2013) used seven datasets at 0.5×0.5 resolution as proxy datasets including (Table 1): the present state of HWB measured by gross domestic product per cap (hereafter income) and infant mortality rate (hereafter IMR); the state of the soil and water resource (hereafter natural resource endowment) measured by the annual renewable water availability and the soil resource measured by the agro-potential; the potential overuse of these resources measured by the population density and the present anthropogenic soil erosion rate; and the available infrastructure approximated by road density. The literature shows causal links of individual indicators to violent conflict. There are two major overlaps between our indicators for quantifying key mechanisms in drylands influencing vulnerability and indicators that are considered most robustly associated with civil war onset and internal armed conflict: Low income and large population consistently

Table 1 Quantification of vulnerability-creating mechanisms: Core dimensions addressed, main vulnerability dimensions, indicators identified and subnational proxy datasets to represent them

Core dimension	Vulnerability dimension	Indicator	Proxy (data source)
Human well-being	Income	Average per capita income	GDP per capita (The World Bank 2006; UNSTAT 2005)
	Distribution of income	Infant mortality	Infant mortality rate (CIESIN 2005)
State of soil and water resource—natural resource endowment	Soil quality	Agro-potential	Productivity of grassland compared to the maximum feasible (Bouwman et al. 2006)
	Water supply	Renewable water resource	Surface runoff (Alcamo et al. 2000)
Overuse of natural resources	Demand for water	Population density	Population density (Klein Goldewijk et al. 2010)
	Soil overuse	Soil erosion (through water erosion)	Water erosion index (Hootsman et al. 2001)
Connectedness	Soft and hard infrastructure	Infrastructure density	Road density (Meijer and Klein Goldewijk 2009)

increase the risk of civil war across many studies (Hegre and Sambanis 2006). The negative relationship with GDP/cap is one of the most robust in conflict literature in general (Hegre and Sambanis 2006), and large population is one of the most robust links to the increased risk of internal armed conflict (e.g., Hegre and Sambanis 2006, Collier and Hoeffler 2004).

Subnational data on infant mortality rates based on 10,000 spatial units were supplied by CIESIN (2005), which we subsequently aggregated from 2.5 $\times$ 2.5 min to the spatial resolution of our study. CIESIN (2005) points out infant mortality as one key proxy measurement for poverty, which in turn Daw et al. (2011) broadly defines as a lack of well-being. The GDP/cap data comprises national-level values. This exception is explained by the following arguments. GDP/cap on a national level was considered important to enable a differentiation between low-, middle, and high-income countries. Furthermore, there is a lack of feasible alternative subnational datasets. We decided not to use the potentially feasible subnational dataset of "gross cell product" per cap (Nordhaus 2006), because of multiple countries in drylands lacking data. This would have ruled out all of these missing cells for the overall analysis. Finally, insights into its subnational differentiation of income distribution are allowed for by its joint analysis with the high-resolution data on infant mortality (Waldmann 1992).

Typology of drylands vulnerability

All data in global drylands were selected and admitted to the cluster analysis. The data mask for selecting drylands is based on the method for drylands characterization used by the CBD (Convention on Biological Diversity Programme, Sörensen 2007). The extent of the global drylands comprised 20,000 grid cells. It is based on an aridity coefficient defined as the ratio of annual precipitation and potential evapotranspiration.

Starting with the indicator data on drylands, Kok et al. (2010, 2013) looked for structures in the indicator datasets using a cluster analysis—employing the established partitioning method of K-means (Steinley 2006). The cluster analysis identified eight clearly distinguishable clusters (or "vulnerability profiles") with typical indicator value combinations describing specific conditions that create vulnerability for smallholder farmers. The eight clusters provide a global overview with subnational detail, thereby showing where they occur in different locations in drylands (see Fig. 1). Importantly, this method keeps the indicators separate so that typical combinations of indicator values of environmental scarcities, overuse, and poverty-related factors can be interpreted, allowing us to relate them to conflict incidence. This contrasts aggregating these indicators to an index, e.g., for a one-dimensional method for ranking which would obscure an abundance of information. The spatial distribution and interpretation of each cluster establish the basis upon which the relation between conflicts and drylands vulnerability will be investigated.

Table 2 shows the characteristics and example locations of the clusters from Kok et al. (2010, 2013) according to the average value for each of the seven indicators. The clusters are categorized into four groups. One group comprises the two clusters occurring in high-income countries (hereafter HICs). The three other groups are located in low- and middle-income countries (hereafter LMICs) and refer to similar natural resource endowments (poor, moderate, and rich). Each group is constituted by two clusters that differ in human well-being and overuse. Examples of

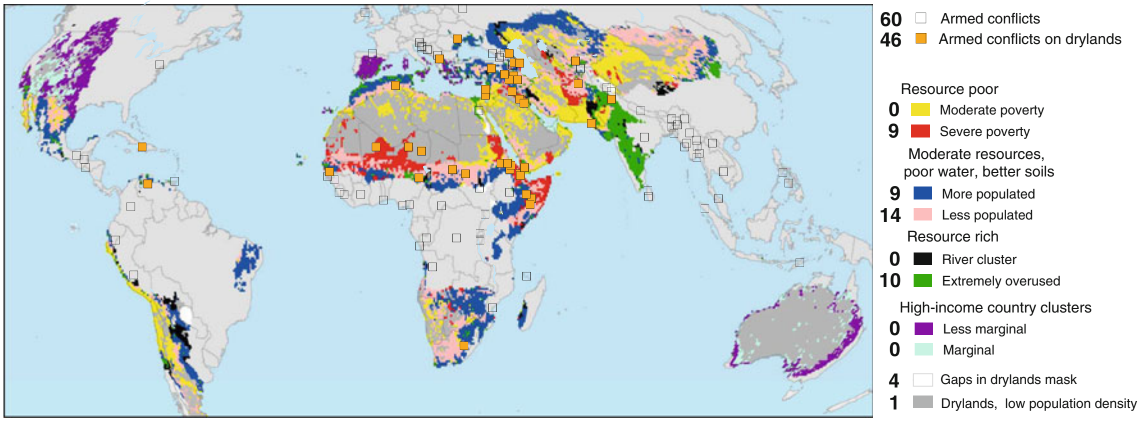

Fig. 1 Spatial distribution of vulnerability of smallholder farmers and armed conflicts in drylands. *Numbers* indicate the conflicts within each cluster

where the clusters are located are given to complement the map of their spatial distribution (Fig. 1).

Violent conflict data

In order to investigate the relation between conflicts and drylands vulnerability, a geo-referenced dataset of violent conflicts is required. We used the following criteria for selecting the conflict dataset: data indicate violent conflicts; conflicts are assigned to a pair of geographical coordinates as opposed to (administrative) units of spatial reporting; global coverage; database dates back to at least 1990. We chose 1990 as the starting point for systemic and data-related reasons. First, this time represents a marked change in the emergence, occurrence, and systemic causes of many conflicts (Harbom and Wallensteen 2007). Second, the focus of our study is on the most recent state of affairs in a time frame for which data availability and quality is best. Finally, both indicator data and ruling out retro-causality with conflicts before 1990 would become more prone to data gaps and less robust the further back in time the conflicts would go due to the stronger reliance on hind-casted modeled data and on observed data with less coverage.

We chose the Armed Conflict Dataset from the Uppsala Conflict Data Program and International Peace Research Institute, Oslo (UCDP/PRIO ACD, version 4-2006, hereafter PRIO ACD) as the violent conflict database. It contains annual entries of armed conflict with at least 25 annual battle-related deaths from 1946 to 2005. PRIO ACD defines armed conflicts as "…a contested incompatibility that concerns government or territory or both where the use of armed force between two parties results in at least 25 battle-related deaths" (Gleditsch et al. 2002). This threshold has been noted to correspond well with violent conflict narratives in view of environmental marginalization (Buhaug 2010; Witsenburg and Adano 2009). All entries from 1990 to 2005 were extracted, regardless of their current state of activeness or inactiveness. This means that other types of conflicts (e.g., social) that do not concern government, territory or both, or violent conflicts without any battle-related deaths are not included.

Multiple conflict years of the same conflict and conflict location were aggregated to one entry, i.e., one conflict point. For example, the multiple entries of the conflict between Israel and the Palestinians, which was assigned one conflict location in the database, were aggregated to one entry for study period from 1990 to 2005.

The PRIO ACD includes one pair of geographic coordinates in decimal degrees (point data) for each conflict entry. According to Raleigh et al. (2006) the center point for one conflict entry defines the midpoint of all known battle locations plotted on a map and is assigned to the nearest 0.25 decimal degree based on visual judgment to make it compatible with the $0.5^\circ \times 0.5^\circ$ spatial resolution of the indicators. The PRIO ACD dataset refined in the above manner comprises 116 armed conflicts.

The conflicts and eight drylands clusters were imported into a geographical information system in order to assign each conflict to one cluster. Conflicts located on the border between two or more grid cells were assigned to the cluster with the largest adjacent number of cells to this conflict. If necessary, this was repeated for the cells surrounding the adjacent cells.

Comparison with common approaches: Country-based cluster index, logistic regression model

In order to make the explanatory power of predicting conflicts in drylands with clusters comparable with the explanatory power of a commonly used multivariate linear regression approach, we calculated a country-based cluster index for each country. The multivariate approach is

Table 2 Summary of drylands vulnerability cluster characteristics and distribution from Kok et al. (2013)

Cluster (color)	Group characteristics	Main characteristics	Examples of locations
Developed, less marginal (purple)	*Very high average income, very low infant mortality rate*	*Very high agro-potential, moderate road density, very high soil erosion mainly caused by cropland irrigation*	*Arid areas of the HICs—mainly in the USA, Spain, Italy, and Australia*
Developed, marginal (light blue)		*Low agro-potential, very low population density and road density, low water availability, low soil erosion through livestock grazing*	
Resource poor, moderate poverty (yellow)	Most resource constrained and isolated areas of the world, very low renewable water resources and agro-potential, low soil degradation; very low water availability, very low population density and road density	Low average income, moderate IMR, moderate HWB	Transition zone between pastoral and sporadic, sparse forms of land use in the desert fringes in America, Africa, and Asia, driest deserts in the world (Atacama, Sahara, central Arabian Peninsula)
Resource poor, severe poverty (red)		Lowest HWB—very low average income, very high IMR, pastoral land use	Arid regions of Sub-Saharan Africa and Asia that are dominated by pastoral land use
Moderate resources, more populated (dark blue)	Low water availability, medium to very high agro-potential, low average income, high IMR, low population density and road density	Very high agro-potential, moderate soil erosion	Parallel bands in steppes and savannahs and neighboring desert areas, with the pink cluster more commonly adjacent to the desert. This typically coincides with a land use gradient from pastoral to agro-pastoral uses
Moderate resources, less populated (pink)		Moderate agro-potential, high soil erosion	
Resource rich, overuse (green)	High natural resource endowment, high water availability	Very high overuse—very high soil erosion, high agro-potential, low HWB; very high population density and road density	Indus River, Tigris-Euphrates river system, Volga River, other irrigated areas like the Aral Sea area, regions adjacent to the eastern Andes
Resource rich, rivers (black)		Moderate HWB (highest in developing country clusters), high disparities, moderate agro-constraints, very high water availability	Indus River, Tigris-Euphrates river system, Volga River, other irrigated areas like the Aral Sea area, regions adjacent to the eastern Andes

The indicated colors are used to identify the clusters throughout this study. Italiced rows indicate clusters in high-income countries, other rows indicate clusters in low- and middle-income countries directly based on the seven underlying indicators, i.e., without the cluster information. Based on the clusters constituting the typology, the country-based cluster index is not a new cluster in the typology but rather the result of making information in the clusters comparable to mono- or multivariate fits on a country by country basis.

The country-based cluster index reflects which clusters cover a country and how many cluster grid cells are within the country. First, we characterize each cluster i by the number of conflicts within the whole cluster divided by the number of grid elements constituting this cluster, resulting in a cluster-specific weight g_i. Then, these cluster-specific values—multiplied by the number of the respective cluster pixels within the country N_i^j—are averaged for each country j. This generates a country-specific conflict proneness CI^j, reflecting the spatial occurrence and dangerousness of the clusters.

$$\mathrm{CI}^j = \frac{\sum_{i=1}^{8} N_i^j \cdot g_i}{\sum_{i=1}^{8} N_i^j} \quad (1)$$

Country-based conflict proneness from the cluster approach and regression analyses are compared with different mono- and multivariate indicator combinations for explaining incidence or lack of conflicts in a country. We expand these comparisons by applying the receiver operating characteristic (ROC, Swets and Pickett 1983) for selecting an optimum model.

Due to the binary response variable (conflict or no conflict in a country), we use the logistic regression model (logit, Hosmer and Lemeshow 2000) to predict the probability of occurrence of an event, i.e., the conflict in a country by fitting the frequency data to a logistic curve. The quality of fit of the mono- and multivariate logit fits was checked with the Akaike information criterion (AIC, Akaike 1974) and the residual deviance (Venables and Ripley 2002). The former can be used as a model selection criterion. It consists of a goodness-of-fit term (Residual sum of squares, RSS, i.e., LogLik) and a penalty term (number of parameters). The latter is comparable with the RSS in linear regression.

Conflict incidence in a typology of drylands vulnerability

Conflict distribution

By using the 116 geocoded armed conflicts as an overlay over the spatial distribution of the eight drylands vulnerability clusters, we gained insights into the distribution of armed conflicts in drylands and non-drylands (Fig. 1). Table 3 summarizes the statistics in terms of area, population, and conflict.

Table 3 General statistics of conflicts in drylands clusters, focusing on their portions with a population density greater than $0.5/km^2$

	Drylands				World
	Area (%)	Pop (%)	Conflicts (total)	Conflicts (%)	Conflicts (%)
Resource poor, moderate poverty	13	5	0	0	0
Resource poor, severe poverty	6	2	8	20	7
Moderate resources, more populated	14	11	10	20	9
Moderate resources, less populated	15	8	13	28	11
Resource rich, rivers	2	2	0	0	0
Resource rich, overuse	5	68	10	22	9
HIC, less marginal	5	3	0	0	0
HIC, marginal	3	1	0	0	0
Total	62	99	41	89	36
pop. dens. ≤ 0.5/km²	36	<1	1	2	1
Gaps in cluster mask	2	1	4	9	3
Grand Total	100	100	46	100	40

Conflicts are proportionally distributed between drylands (46 conflicts, 40 %) and non-drylands (70 conflicts, 60 %), with respect to land mass area (roughly 33–66 %). Thus, drylands are as conflict prone as non-drylands. This hints at an insufficient mono-causal explanation of conflict occurrence through water scarcity—a main characteristic of drylands. In contrast, conflict distribution in drylands is heterogeneous and concentrated. By only taking drylands areas into account with a population density greater than $0.5/km^2$ (thus excluding one drylands conflict in the resource poor, severely impoverished red cluster), 91 % of drylands conflicts are concentrated in four clusters that cover 40 % of the total drylands area (Table 3), amounting to 36 % of the 116 aggregated conflicts worldwide between 1990 and 2005. These four clusters are neither the most populated ones nor do they have the highest population density, raising initial questions about some of the broader neo-Malthusian claims about population pressure leading to conflict in drylands.

All 46 drylands conflicts are located in LMICs, while the other four are conflict free (see Table 3 and Fig. 1—they can both serve as a lookup tables for the cluster names and associated colors throughout the study, while Table 2 characterizes the clusters). Two of the conflict-free clusters ("HIC cluster, marginal", light blue and "HIC cluster, less marginal", purple) are in HICs, and two (resource poor, moderate poverty, yellow cluster and the resource-rich river cluster, black) are in LMICs. Four conflicts are located in unclassified drylands where the cluster analysis does not cover the CBD drylands mask. Conflict incidence also differs in developing country clusters with different levels of HWB, natural resource endowments, and degrees of overuse; 50 % of all drylands conflicts fester in the two "poor water, better soils" clusters with moderate natural resource endowment alone (dark blue and pink), and the second resource-rich cluster "overuse" (green) is also disproportionately prone to conflict (22 %), despite occupying a mere 5 % of all drylands areas. Only 2 % of people living in drylands live in the most impoverished "resource poor, severe poverty" (red), yet it is severely hit by conflict (20 %).

A more formal problem is needed to be addressed in this context with respect to retro-causality. Due to the fact that we are using the spatial distribution of typical value combinations of datasets from 2000 (and water availability from 2005, see Table 1) for explaining conflicts in the PRIO ACD database from 1990 to 2005, the question arises whether the conflicts are influencing the indicator values, vice versa, or both. For example, Witsenburg and Adano (2009) indicate that negative consequences of conflict have wide spillover effects on many aspects of HWB in drylands. We addressed the question of retro-causality by comparing cluster results of the same indicators, but using data from 1990, to the results this study is based on (2000 and 2005). Comparing the results revealed the same number of clusters (eight), and highly stable vulnerability profiles and locations thereof, showing that the clusters and according vulnerability profiles already exist in the data from 1990. This result suggests that conflicts have not measurably influenced the indicator data. The sole reclassification of grid cells exceeding 1 % of the overall drylands grid cells is from the "resource poor, severe poverty" (red) to "resource poor, moderate poverty" (yellow) cluster (2 % of all drylands grid cells).

In conclusion, we find that armed conflicts are heterogeneously distributed across drylands with respect to the clusters, i.e., vulnerability profiles, ruling out population density and low precipitation as premature causes. While less impoverished profiles are less conflict prone, profiles with similar levels of poverty, overuse, population density, or natural resource scarcity show differences in conflict incidence. The next section discusses in how far these differences can be quantitatively explained with mono- and multivariate fits, and on the basis of the drylands typology.

Comparison with mono- and multivariate fits

This section addresses whether the method establishing the drylands typology has measurable added value over directly using the underlying seven indicators in a logit approach (Hosmer and Lemeshow 2000). We chose the country level as the spatial unit of investigation for this. In the case of the logit approaches, the explaining variables are the countrywide averages of the indicators from Table 1. In the case of using the indicators via the typology, the explaining variable is the country-based cluster index as defined and described in Sect. "Comparison with common approaches: Country-based cluster index, logistic regression model". The explained variable is the conflict occurrence in a country between 1990 and 2005. The conventional linear fits include monovariate regressions with all seven indicators, a bivariate fit using income and IMR to represent HWB, and a multivariate fit using all seven indicators, including natural resource conditions and their use. Finally, we compare these with the monovariate fit using the country-based cluster index.

As a first measure for the quality of fits, we take the averaged deviance from the explained variable (residual deviance, solid line in Fig. 2) which allows for comparing the quality of the different models. Within the monovariate approaches, IMR yields the best explanation. Using this variable together with income slightly improves the result, while including the natural resource conditions and use improves the result considerably. To exclude the possibility that this improvement is mainly due to the increased number in degrees of freedom in the 7-variable model, we applied the AIC (dashed line in Fig. 2) which compensates

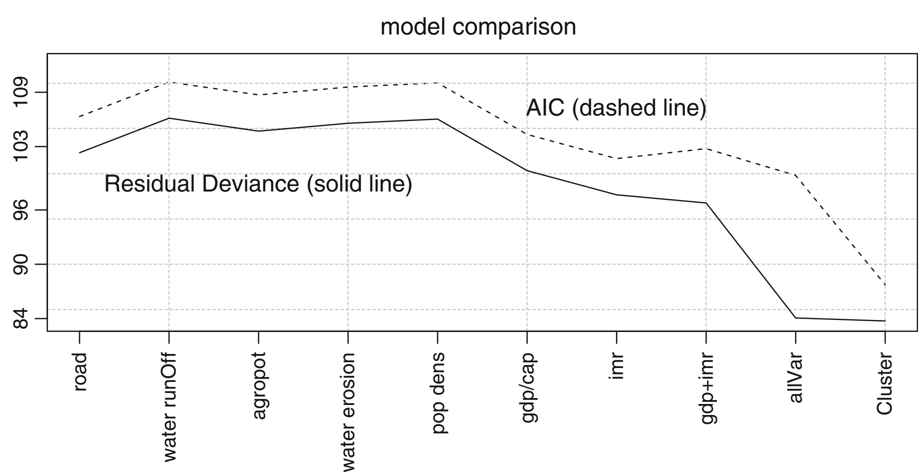

Fig. 2 AIC and residual deviance for the models. AIC and residual deviance for comparing the models of the monovariate logit fit for each of the seven drylands indicators, the multivariate logit fits for income and IMR, all drylands indicators, and the country cluster index as the explanatory variable. Smaller values denote better fits. See Table 1 for full indicator names

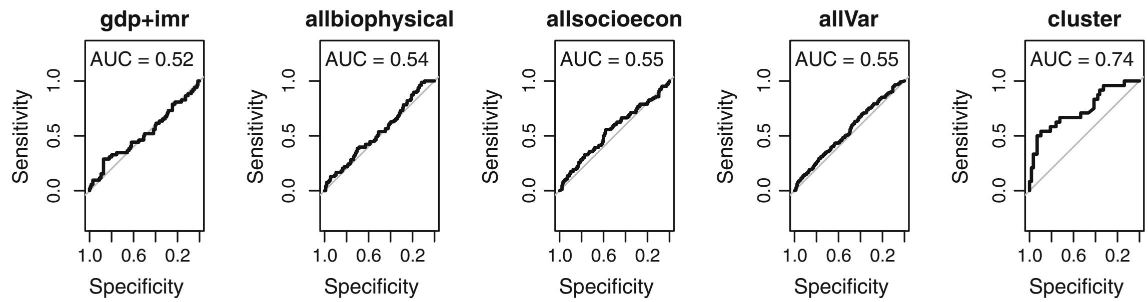

Fig. 3 ROC for comparing the models of the multivariate logit fits for income and IMR, biophysical indicators, socioeconomic indicators, all drylands indicators, and the country cluster index as the explanatory variable (from *left* to the *right*)

for this effect. As the AIC improvement is also significant (although less impressive), we can conclude that in a multivariate logit framework, the occurrence of conflicts is explained best by a combination of socioeconomical and natural variables.

Now, we compare the quality of the logit approach with the quality of cluster-based conflict explanation. The last column in Fig. 2 shows that by using this variable in a monovariate logit approach, both the residuals and the AIC are further reduced compared to the multivariate fit using all indicators (allVar). While the residual deviance only improves slightly, the AIC shows a large improvement due to the strong reduction in degrees of freedom. This means that the monovariate regression based on the nonlinear clusters is the preferable model for the statistical explanation of conflict occurrence.

Evaluating the same set of models in a receiver operating characteristic (ROC) also leads to the preference of the nonlinear method (Fig. 3). The ROC is a graphical plot, showing the true positive rates (sensitivity) versus false positive rates (specificity) in predicting conflict incidence or absence with the country indices. The area under curve (AUC) indicates the accuracy of the test or the ability of the model to correctly classify country indices with and without conflict (perfect classification being 1.00). Points on the diagonal line of no-discrimination (AUC = 0.50) represent random guesses. Figure 3 shows how the models with income and IMR (AUC = 0.52) and all variables (AUC = 0.55) are largely random in terms of predicting a conflict incidence or absence. The model using the nonlinear cluster information shows significantly higher predictive power (AUC = 0.74) in discriminating between countries with and without conflict.

In conclusion, comparing these quantitative approaches for predicting violent conflict incidence suggests that the nonlinear cluster approach is preferable over linear fits by showing measurable added value in both cases. This hints at the importance of dependencies between the explaining variables for explaining conflict incidence, which are not considered in multivariate linear regression and logit fits.

Linking conflict incidence to cluster interpretations

To additionally obtain a qualitative understanding of the relation between the vulnerability profiles and conflict occurrence, and of the dependencies between explaining variables, we now interpret the clusters as characterized by the seven normalized indicator values of each cluster's center, focusing on the dimensions of natural resource endowment, HWB, and overuse they constitute (Fig. 4, left). The dimensions and indicators constituting them were introduced in Sect. "Vulnerability generating mechanism in drylands" and Table 1. Reflecting the structure in Fig. 4, left, from top to bottom, the interpretations are subsequently grouped into differential analyses of LMIC clusters based on their low, moderate, or high natural resource endowments in the following three subsections. Using the same grouping based on similar natural resource endowments, these sections provide the basis for the summarizing schematic diagrams (Fig. 4, right) of how the typology of socio-ecological vulnerability in drylands relates to violent conflict distribution using a nonlinear combination of these dimensions. These schematic diagrams are discussed in the subsection thereafter, concluding with whether the differential qualitative analysis of clusters provides explanations for the measurable added explanatory power shown in Sect. "Comparison with mono- and multivariate fits".

The two conflict-free clusters in HICs display significantly higher HWB than in the other clusters and are left out of the interpretation and schematic diagrams. This is justified by the different context in the higher income countries, requiring a different approach for analyzing conflicts (Markakis 1995).

Resource-poor clusters show contrasting conflict proneness and HWB

The resource-poor clusters show contrasting HWB (Fig. 4, left, top). The yellow cluster (moderate poverty) has the second highest average income and the lowest IMR of any developing country cluster and is the only cluster out of

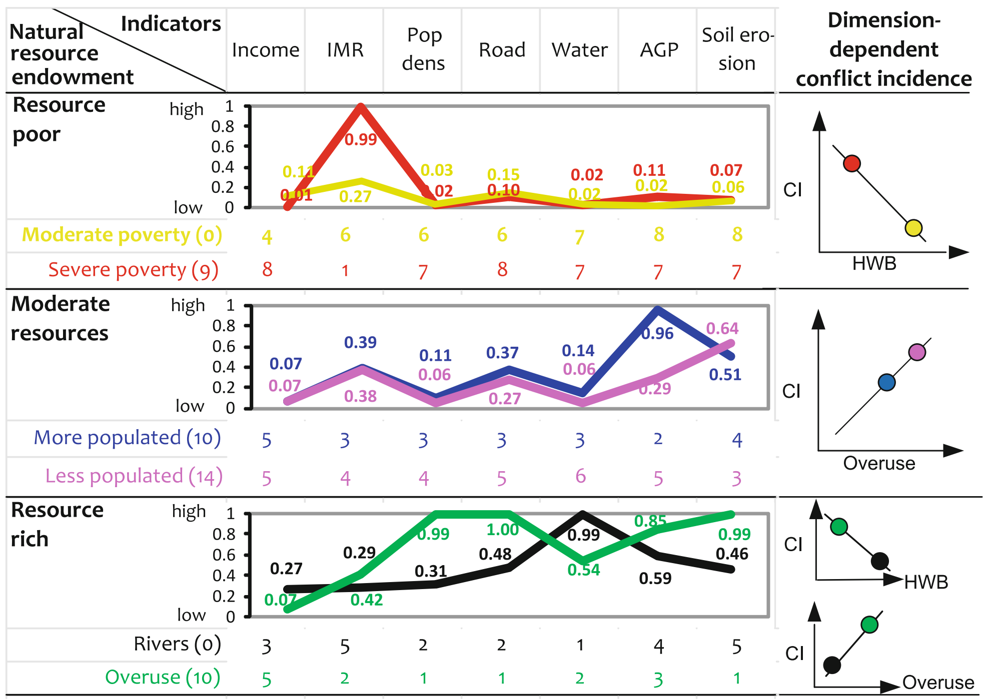

Fig. 4 *Left*: Vulnerability profiles of the six clusters prevalent in LMICs grouped based on poor, moderate, or rich natural resource endowment, ranks of indicator values across all eight clusters (1: highest), and number of conflicts in parentheses. The indicator values are min–max normalized between 0 and 1. The reading of the indicator ranges is from "low" (0), to "high" (1), as opposed to from "adverse" to "favorable". Column header abbreviations for indicators: Income: Average per capita income; IMR: Infant mortality rate, Pop dens: Population density, Road: Infrastructure density; Water: Renewable water resource; AGP: Agro-potential; Soil erosion: Soil erosion (through water erosion). *Right*: Schematic diagrams of conflict incidence as a function of the dimensions of natural resource endowment, HWB, and overuse. CI means conflict incidence; Human well-being (HWB) is a function of average per capita income and IMR; Overuse is a function of soil erosion and population density. For each group of similar natural resource endowment, the circles with colors corresponding to the clusters colors show how the conflict incidence (*y* axis) relates to different degrees of HWB or overuse (*x* axis). The black diagonal lines show the direction of change in conflict proneness when changing the independent variables on, and the distances between circles approximate the differences

five with low HWB without conflict. At the same time, it displays the most resource-poor situation overall, resulting from natural conditions as opposed to overuse (lowest soil erosion). Its relative wealth is not based on agriculture. In consequence, livelihoods are predominantly based on other, less marginal resources and services, making conflicts over natural resources less likely than in the red cluster (severe poverty). Table 2 and Fig. 1 provide insights into the locations of these clusters.

The comparably dramatic resource situation in the red cluster translates into the highest IMR and the lowest income by far, and into relatively high conflict incidence. Pastoral livelihoods in the poorest cluster covering arid regions of Sub-Saharan Africa and Asia are based on the scarcest water resources and extremely limited agro-potential. Hence, the resource situation resulting from natural conditions can be further exacerbated by extensive grazing or nomadic grazing and lead to desertification (Geist and Lambin 2004). This can threaten their livelihood basis and, according to the dryland livelihood paradigm, may subsequently lead to (further) poverty and violent conflict (Safriel and Adeel 2008). Furthermore, this cluster hosts the most sparse population density and lowest road density. Conflicts in the red cluster include conflicts between Ethiopia and the Afar revolutionary democratic Union front (ARDUF), Niger and the front for democratic renewal, and Mali and the Northern mali tuareg alliance for change.

Clusters with moderate resources and low HWB show highest conflict incidence

Twenty-four out of 42 drylands conflicts (almost 60 %) are located in the two clusters with moderate natural resource endowment and low HWB (Fig. 4, left, middle). They show very high conflict incidence under high overuse (pink cluster, 14 conflicts), and less overuse and high incidence under high agro-potential and slightly higher population density (dark blue cluster, 10 conflicts). They exhibit virtually identical values of low water resource availability/cap, low income, and moderate IMR.

The pink cluster shows the highest conflict incidence. Although its water stress is less severe than in the yellow cluster, the over-used soils and limited agro-potential may not allow sound livelihood alternatives to secure a living standard under additional external pressures. Thereby it points to a particularly severe situation that limits people's capacity to cope with any disturbances if they rely on the limited agricultural productivity for a living, while the much higher agro-potential in the dark blue cluster offers alternatives. Both clusters show high conflict proneness despite HWB values similar to the conflict-free yellow cluster, indicating that an explanation through poverty and resource scarcity alone is insufficient in their case.

Conflicts in the pink cluster include border conflicts between Eritrea and Ethiopia, Somalia and Ethiopia, conflicts in Lesotho and Botswana, and Uzbekistan and the Jihad islamic group. Conflicts in the dark blue cluster include conflicts between Macedonia and the national liberation army, Turkey and the Kurdistan's Worker Party, and Venezuela and the Military Faction under Hugo Chávez.

Resource-rich clusters show contrasting conflict proneness and HWB

The highest water availabilities and 2nd and 3rd highest agro-potential in the black ("rivers") and green ("overuse") clusters constitute the highest natural resource endowments. Similarly to the extremely resource-poor counterpart, the pair shows contrasting income correlating with high or no conflict incidence (Fig. 4, left, bottom).

The conflict-free black cluster is characterized by moderate agro-potential, soil degradation and population density, and the highest water availability. This allows for moderate agricultural production enough for creating relative wealth. It is the only cluster with a moderate level of HWB in LMICs, with potentially conflict-incidence-reducing effects. On the other hand, this peace may be fragile as the high IMR points toward significant socioeconomic disparities among the population. These disparities and related distributions of resources may induce future conflicts.

In the green "overuse" cluster, the relatively good natural resource conditions are critically overstretched by a very high population density (68 % of the drylands population, 5 % of drylands area), inducing the highest soil degradation and highest pressure on resources. The second highest water availability and a high agro-potential is translated into levels of HWB lower than in the moderately endowed clusters. In face of abundant yet overused resources, people reliant on these resources to ensure their livelihoods are more likely come into conflict if the resources are depleted and no sound alternatives exist. Conflicts located in this cluster include conflicts between Israel and Palestinian factions, Lebanon and the Lebanese Army (Aoun), India and Sikh Insurgents, and Moldova and the Pridnestrovian Moldavian Republic.

Qualitative and quantitative support for a nonlinear and multi-causal explanation of conflict incidence

In conclusion, differential qualitative analysis of clusters classified through the dimensions of natural resource endowment (water resource availability and agro-potential), HWB (average per capita income and IMR), and overuse (soil erosion and population density) offers explanations for why the nonlinear models provide measurable added explanatory power. It does so by interpreting the number of conflicts in each cluster in the light of dependencies between these dimensions.

These results are synthesized in the following paragraphs and in the schematic diagrams in Fig. 4, right, using the same groupings of clusters based on low, moderate, and high natural resource endowments (from top to bottom). Pointing out tendencies, the two-dimensional diagrams in Fig. 4, right, have a predominantly conceptual and qualitative character rather than a quantitative one (see caption of Fig. 4, right for details). The combination of indicators was principally motivated in Sect. "Vulnerability generating mechanism in drylands" and Table 1. They are combined to aggregated variables in the schematic diagrams (x axis) as follows: the lower IMR and higher income is, the better HWB is, and vice versa; the higher the soil erosion and population density are, the higher overuse is. As we are dealing with a discrete typology, the changes are taken from the comparison of the two considered clusters.

In similar resource conditions, conflicts occur when marginal and/or over-used natural resources coincide with more severe poverty (Fig. 4, right, red cluster, green cluster). Less overused, or less marginal, resources are always less conflict prone (a-yellow, b-dark blue, c-black). HWB is the distinguishing dimension in extreme resource endowment cases (a, c), while overuse is in cases where natural resource endowment is sufficient for agricultural use beyond subsistence (b, c).

In this light, we conclude that resource scarcity is not a generally applicable explanation for conflict incidence in drylands. In the relatively resource-rich environments, income and population-density-driven soil degradation differentiates between conflict proneness and its absence (Fig. 4c). Yet, this finding is not applicable when comparing clusters with significantly different resource endowments (Fig. 4a–c). For example, conflict-prone clusters with fewer resources have far lower population density than the conflict-free "rivers" cluster. This indicates how the importance of HWB and overuse in explaining conflicts depends on a further dimension: The level of natural resource endowment appears to decide whether the HWB (through income and IMR) or overuse (through soil degradation) determines the conflict proneness.

With these findings, the best explanation of conflict incidence through the cluster-based logit approach (Fig. 2) and through the ROC (Fig. 3) becomes understandable: As shown in Fig. 4 the importance of the variables for the dimensions of HWB and overuse in explaining conflicts is different depending on the natural resource endowment. Such a relation can never be reproduced by a linear regression where the influence of a specific variable is necessarily independent from the values of the other variables.

From that we can understand why the vulnerability profiles from the cluster-based approach explain armed conflict incidence in drylands better than linear regression approaches and conclude that in the case of explaining conflict incidence with variables indicating vulnerability-generating factors in drylands, a nonlinear approach allowing for such dependencies is the preferred method.

For what this means quantitatively for the relationship between these dimensions and conflict proneness, we discern the ranges of indicator values that can always be associated with conflicts by taking the upper and lower quartiles (i.e., 50 % of the grid cell values around the median value) of each indicator in each cluster into account. In the poverty dimension, this applies to an IMR of 66 deaths per 1,000 live births and higher (compared to an overall drylands range of values from 0.02 to 252.93 deaths), and a GDP/cap of USD 558 and less, (drylands range USD 122–34,560); in the overuse dimension, it applies to a population density of 126 people per km^2 and higher, or 0.5 and less (drylands range 0–300 people per km^2), and a water erosion index of 0.29 and higher (drylands range 0–0.58); in the natural resources dimension, it applies to an agro-potential of 0.005–0.015 KgC/m^2, and 0.254 KgC/m^2 and higher (drylands range of 0–0.55 KgC/m^2); runoff 6.5–326.4 10^{3}m^3/(year*km^2) [drylands range 0–500 10^{3}m^3/(year*Km^2)].

In addition, we compare the averages of the indicator values to discern what degrees of resource endowment, human wellbeing, and overuse are generally associated with either peace or conflict. With respect to the dimension of natural resource endowment, the lowest averages without conflict are a water runoff of 10.3 10^{3}m^3/(year*km^2) (yellow cluster) and an agro-potential of 0.005 KgC/m^2 (i.e., kilograms of carbon when cultivating grassland, yellow cluster). Slightly less resource scarcity is associated with conflict in the red cluster. The highest averages that show conflicts are 229 10^{3}m^3/(year*Km^2) for water runoff (green cluster) and 0.26 KgC/m^2 for agro-potential (dark blue cluster). With respect to the dimension of poverty, the most severe averages without conflict are a GDP/cap of USD 2,995 (yellow cluster) and 43 deaths per 1,000 live births (black cluster). The least severe averages that still have conflicts are USD 2,064 and 58 deaths per 1,000 live births (both pink cluster). With respect to the dimension of overuse, the highest averages without conflict are a water erosion index of 0.177 (black cluster) and a population density of 79 people per km^2 (black cluster). The lowest averages that show conflicts are a water erosion index of 0.03 and 6 people per km^2 (both red cluster).

Ground truthing—exemplary conflict causes in the Horn of Africa and vulnerability profiles

This section investigates in how far general interpretations of conflict incidence with the vulnerability profiles in the light of the vulnerability-generating mechanisms are viable for specific conflicts in the drylands sample. We relate the causes and locations of drylands conflicts in the Horn of Africa, i.e., in Ethiopia, Eritrea, Somalia, and Djibouti, to the pertinent profiles. The first three countries are among the 20 countries in the world with the lowest income (CIA 2012). “The Horn” has the highest conflict density in global drylands (8 out of 42 conflicts) and is a classic example for environmental degradation (Markakis 1995). Figure 1 shows that three vulnerability profiles are associated to this region (red, pink, and dark blue). Human–environment systems reflected here include the predominantly subsistence-based pastoral use in lower-lying areas under poor-to-severely poor human well-being, very low water availability, and low population density in the red and pink clusters (Eritrea, Djibouti, Somalia, and Danakil depression, Afar Region, Ogaden Province in Ethiopia), and agropastoral use in less water scarce, more mountainous regions with higher agro-potential in the blue cluster (more mountainous regions in Ethiopia). Five conflicts are in the pink cluster, and two more are immediately adjacent to it.

In the following, we investigate conflicts involving the Afar people and the states of Ethiopia and Djibouti in more detail, and discuss two that are directly related to the Ethiopian–Eritrean disputes (Raleigh et al. 2006). To different degrees, these conflicts are related to socioeconomic, biophysical factors, and political factors.

Conflicts involving the Afar—red and pink clusters

The two conflicts in this area are between the ARDUF, and the Ethiopian government (red profile), and between the neighboring conflict between the Afar aligned FRUD (Front for the Restoration of Unity and Democracy) and the Djibouti government—backed Issa Tribe (pink profile).

The Afar region on the northeastern Ethiopian frontier is a low-lying depression that exhibits high mean temperatures and very low annual precipitation sums. It is largely assigned to the red cluster, showing the lowest natural resource endowment and severe poverty. The Afar people are one of the main pastoral groups in the Horn of Africa, and mobile pastoralism is the dominant type of land use (Rettberg 2010). Inter-clan conflict over scarce resources is a major conflict cause (Berhe and Adaye 2007) but nationalism (e.g., Afar against Issa in Ethiopia and Djibouti) and competition for power between political parties also play a role.

In the past, resources have been constrained for the Afar through droughts and floods (Rettberg 2010), and also through the Ethiopian government's installation of large centralized farms in the region where sufficient agro-potential exists. This has cutoff the Afar's resource base from important land and water resources (Getachew 2001; Markakis 2003; Rettberg 2010), contributing to the breakdown of long-standing and effective coping mechanisms, e.g., against natural resource scarcity and variability, and driven the pastoral communities into more severe poverty. How this fragile socio-ecological system exposed to environmental variability and non-inclusive government policies is empirically linked to conflict in the Afar region agrees well with our hypotheses of conflict caused within the red profile (Fig. 4 top and text), where we argue that further restrictions of the resource base can subsequently threaten the livelihood base and lead to violent conflict.

Similarly, the second conflict involving the Afar and Djibouti—backed Issa Tribe—is over grazing lands they were forced off of and further compounds the problems outlined above (Rettberg 2010). It is located in the pink profile. We argued that despite more favorable HWB and natural resources than in the related red profile people's capacity to cope with additional external pressures is limited due to their reliance on limited agricultural productivity and a lack of livelihood alternatives (Fig. 4 top and text). This can cause or prolong conflict, and deteriorate into the poorer and more resource-sparse red profile, which it is commonly adjacent to (e.g., in the low-lying regions along the Ethiopian Border to Djibouti and Eritrea, and the Red Sea coast).

With respect to the causal relatedness with the indicators used for the cluster analysis, conflict-relevant statements from case study literature (Berhe and Adaye 2007; Getachew 2001; Markakis 2003; Rettberg 2010) about conflict causes in the Afar Region are consistent with conflict interpretations through the profiles. While livelihood alternatives to secure a living standard are limited and can facilitate conflict under additional external pressures in the red and pink profile, this does not apply to the dark blue profile which is nearly conflict free in the Horn of Africa. Extremely high agro-potential and less overuse make it less vulnerable to disturbances of the resources base which allows for agropastoral use beyond a subsistence basis. As a result, pastoral areas are more conflict prone than areas sufficient for agropastoral and alternative livelihoods, and a lack thereof in the red and pink profiles appears to pose enough adverse boundary conditions to foster conflict—acknowledging the room for further conflict causes.

Discussion

Our results show that systematic quantitative and qualitative relationships exist *between* environmental and socio-ecologic factors that explain the distribution and incidence of violent conflict in drylands without including political variables. Differential qualitative analysis of typical value combinations of these variables provided explanations for the measurable advantages of this nonlinear approach over commonly used linear fits. Nevertheless, the modeling results in Figs. 2 and 3 show that there is room for improving of statistical explanatory power in follow-up studies. In this light, we discuss three relevant aspects in the following: the availability of global subnational datasets, the incorporation of political factors and rigorous regional, and high-resolution validation.

Interpreting the distribution and incidence of violent conflict case studies in the Horn of Africa through the vulnerability profiles leads to plausible, consistent results. It also indicated a situation where additional indicators would be useful to describe further relevant local conflict causes, pointing out directions for follow-up studies—two conflicts from the drylands sample that are directly related to the Ethiopian–Eritrean border conflict between the Eritrean and Ethiopian government, and between the Ethiopian government and EPLF (Eritrean People's Liberation Front). Here, Lata (2003) showed that political factors are important.

One impediment for accounting for all the underlying local mechanisms driving conflict in a global study of vulnerability is the scarcity of relevant, spatially and temporally well-resolved socio-political data with subnational resolution (Blattmann and Miguel 2010; Sietz et al. 2011). With respect to the political dimension and feasible datasets to formalize it, such studies should focus on including data on political marginalization (Buhaug 2010) and governance issues (Salehyan 2008, Getachew 2001). While the global availability of such data on these aspects is limited, this may further systematize conflicts in drylands by moving toward a "socio-ecological-political" typology to further reduce the unexplained variance. Exemplarily, incorporating an adequate indicator for political marginalization would likely reduce the unexplained variance in our model introduced in Sect. "Comparison with mono- and multivariate fits". Detailed statements on how this might influence our results are more speculative, because compiling this indicator for global and spatially explicit subnational studies would be more challenging. The inverse world governance indicator of voice and accountability is a candidate. On a national basis, it captures citizen's ability to participate in selecting their government, as well as freedoms of expression and association (Kaufmann et al. 2008), yet would mask subnational variations, group, or community marginalization. Combining it with a geocoded subnational dataset on ethnic power relations (Wucherpfennig et al. 2011) for identifying all politically relevant ethnic groups and their access to state power may resolve this issue.

We account for critical socioeconomic and environmental factors specific to drylands vulnerability. The typology, i.e., variable value combinations, offers systematic explanations for violent conflict incidences in drylands with a limited set of variables. If the political dimension were the sole dominating driver of violent conflict in drylands, the systematic behavior of socio-ecological variables would not be discernible. The debate on the role of natural resource factors in explaining violent conflict exemplarily shows that factors for explaining violent conflicts, or conflict types, in separate studies are not always equally significant. In our point of view, this further suggests that it is more promising for large-N studies to account for varying importance of explaining variables, and interdependencies between them, in their research design. For example, in a comprehensive statistical analysis of empirical results from numerous other studies linking factors to violent conflict onset, Hegre and Sambanis (2006) confirm the robustness of the relationship between two key variables of income (negative) and population (positive) with the risk of internal armed conflict, respectively. A third key variable, the length of peacetime until the conflict outbreak (negative relationship), is only robustly significant for a certain type of violent conflict.

In principle, the plethora of locally important factors that generate drylands vulnerability and also pose links to the incidence of conflicts such as the scarcity and management of natural resources (Sietz et al. 2012) can inevitably be reflected only to some extent when working at a global scale. Nevertheless, in dealing with the complexity of drylands, Sietz et al. (2011) have provided valuable insights into drylands vulnerability reduction at this scale. Their findings deduce thematic and spatial entry points for vulnerability-reducing measure based on a typology of drylands vulnerability and support the prioritization of strategies for improved drylands development. Insights gained at the global scale are suitable to stimulate local to regional investigations in order to further elaborate the knowledge established so far. Reflecting on the limitations of working at a global scale, typical mechanisms identified at the global scale were further specified in the contexts of the Peruvian Andes and Northeast Brazil (Sietz et al. 2012, Sietz 2013). These regionalizations indicate possible approaches to refining the insights gained in the conflict-oriented context of this study or comparable studies to further understand violent conflict in drylands.

Conclusions

This study applied results from a nonlinear and spatially explicit methodology emanating from global and environmental change research for analyzing vulnerability on drylands to a peace research-related problem. Motivated by an inconclusive debate over implications of resource scarcity for violent conflict, and prevalent reliance on national data and linear models for explaining conflict in the literature, the study addressed a lack of studies on the socio-ecological vulnerability–violent conflict nexus in global drylands on a subnational level. We conclude this study with the potential broader significance of its methodological and content-related findings for what drives peace and conflict in drylands, and by suggesting future research for expanding on similar approaches.

Following Reynolds et al. (2007), Safriel and Adeel (2008) proposed that "…much of the controversy over the biophysical and social dynamics of livelihoods in the drylands can be resolved by recognizing that these processes may be non-linear" (p.121). Acknowledging this, we argue that this may also be the case in the controversy over the role of resource scarcity in explaining violent conflict in drylands. This is what the findings of our study on armed conflict distribution suggest when analyzed through the lens of a typology of socio-ecological vulnerability. While large-N studies commonly rely on essentially linear research designs, we argue that nonlinear research designs may allow a more nuanced view and argumentation when aiming for regional and global overviews, yet considering local specifics, as supported by O'Loughlin et al. (2012) and Hsiang et al. (2013). Importantly, while non-linearity is discussed in the debates, e.g., on the implications of climate change on violent conflict (e.g., Buhaug et al. 2008), it is not well represented in methodologies to investigate what drives violent conflict. This may explain why empirical and quantitative research focusing on general relationships between resource scarcity and violent conflict are the subject of much debate: variations of importance of factors across these regions, e.g., drylands, can be substantial (e.g., O'loughlin et al. 2012). The method applied in this study may contribute to disentangling these variations.

We found that conflict incidence is heterogeneously concentrated across global drylands according to typical profiles of socio-ecological vulnerability. Four profiles distributed across low- and middle-income countries comprised all drylands conflicts. We showed that conflict occurs in all degrees of natural resource endowments of these profiles. We found that conflict proneness nonlinearly decreased with increasing human well-being. In similar endowments, conflict generally increased with lower endowment and/or more overuse. In low and high endowments, conflict was absent when less overuse converged with less human well-being, i.e., less poverty and higher income. Generally, the most adverse averages of poverty and income in systems without conflict were GDP/cap of USD 2,995 and 43 deaths per 1,000 live births. The highest averages of overuse without conflict are a water erosion index of 0.177 and a population density of 79 people per km^2. The lowest averages resource endowments without conflict are a water runoff of 10.3 $10^3 m^3/(year*km^2)$, with an overall range in drylands from 0 to 500 $10^3 m^3/(year*Km^2)$ and an agro-potential of 0.005 KgC/m^2 (i.e., kilograms of carbon when cultivating grassland, drylands range from 0 to 0.55 KgC/m^2).

Conflict does not generally increase with resource scarcity or overuse. A systematic explanation of conflict incidence and absence across all different degrees of natural resource endowments is only reached through varying importance of human well-being and resource overuse depending on the level of endowment—a relationship that is irreproducible by commonly applied linear regression or mono- or multivariate logit models. This showed that the influence of these factors—in this case socioeconomic and environmental—is dependent on their value combinations and that a methodology that accounts for this leads to better understanding of violent conflict and its absence in drylands. If the political dimension was the sole dominating driver of violent conflict in drylands, the systematic behavior of socio-ecological variables would not be discernible. We expect including this dimension will further reduce the unexplained variance in the model in case appropriate subnational proxies covering global drylands are derived for future studies.

We concluded that resource scarcity is not a generally applicable explanation for conflict incidence in drylands. Conflict and peace are prevalent under similar scarcities of natural resources in socio-ecological systems. Closer inspection of their vulnerability profiles showed that under poverty, both naturally scarce and better endowed yet overused natural resources drove violent conflict. On the other hand, very similar low income was observed in both conflict-free and conflict-ridden profiles. To our opinion, this showed that two "extreme" positions of purely resource-scarcity-induced conflict ("neo-Malthusian" position, Homer-Dixon 1991) or purely economically/socially/politically induced conflict ("Durkheimian" position, Shaw and Creighton 1987) provide the most insight into the distribution and concentration of violent conflict incidence in drylands when they are combined, ruling out mono-causal and blanket statements.

Regional or global research using more localized data on conflict has commonly been proposed as a primary next research step in terms of quantitative studies of environmental change influencing violent conflict incidence (Buhaug 2010; Burke et al. 2009). Using increasingly improved and available geo-referenced and disaggregated conflict datasets for Africa, such as the Armed Conflict Location and Event Data (ACLED, Raleigh et al. 2010) and the Uppsala Conflict Data Program Geo-referenced Event Dataset (UCDP GED, Sundberg et al., 2011), could corroborate the added values of this study by testing the outcomes in a more disaggregated approach and with data including recent conflicts from 2006 to 2011. This would allow for a more rigorous validation of our findings in line with newer validation studies (e.g., Krömker et al. 2008; Fekete 2009; Sietz et al. 2012) to further strengthen the credibility of our study. This would also provide a setting to test the method with different types and definitions of violent conflict by investigating how they relate to the socio-ecological typology of vulnerability.

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