Deutscher Tropentag 2004
Berlin, October 5-7, 2004

Conference on International Agricultural Research for Development

Agricultural Development Patterns and Soil Degradation in Asia
- A regional analysis based on multivariate data analysis and GIS -

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Abstract
Soil degradation is a widespread problem in many Southeast Asian countries. Competing hypotheses exist about links between socioeconomic factors and soil degradation, with population pressure and poverty being among the most often cited factors for soil degradation. This paper aims at providing a better understanding of the existing links by conducting a statistical analysis at a regional level. The analysis is based on secondary geo-referenced data on soil degradation and agricultural development, as well as additional tabular poverty data. Data integration is performed in a Geographic Information System (GIS). An analytical framework is used, in which the influence of causal factors of soil degradation depends upon the agricultural framework conditions. In order to capture these varying causal relationships, the sample is first grouped into agricultural development clusters using multivariate methods. Subsequently, the incidence of soil degradation within clusters is analyzed. Last, the causes of water erosion are quantified using ordered regression analysis. Results show clear differences with regard to the severity of water erosion by cluster. A strong relevance of poverty and population density for water erosion is found. If significant in models, population density and poverty show positive relations with water erosion. The approach proves useful to provide better knowledge about critical constellations of natural, socioeconomic and land use factors with regard to soil degradation and to enhance prospects for geographic targeting of measures to prevent soil degradation.

Introduction
Socioeconomic factors are considered as crucial for the state of soils and have been found to be of empirical relevance on a worldwide scale (Kirschke et al. 1999). In the developing-country-context, poverty and population density are among the most often cited causes of soil degradation. Yet, the understanding of links between socioeconomic factors and soil degradation remains limited, while competing hypotheses exist. The debate between a "Boserup" optimistic view of sustainable adaption to population growth and a "Malthusian" pessimistic view of a limited growth rate of agricultural production that cannot keep up with high population growth rates is not yet settled and different empirical evidence is shown (e.g. Templeton/Scherr 1997 for an overview of studies). Similarly, poverty is considered to make land a more valuable and thus protected asset for the poor, since it is often all they depend upon. On the other hand, several aspects combine to shorten the time horizon of poor people's decisions, thereby inhibiting soil protection measures that pay off in the future (Lipper 2002). The puzzle has been untangled partly by looking at different factors conditioning the relationships between e.g. population growth and soil degradation (Pender 1999). Often, property rights are discussed as crucial for the outcome. This calls for further empirical analysis differentiating the potential causes of water erosion by agricultural conditions.
Several efforts have been made to assess the extent of soil degradation at a regional and worldwide scale. For Asia, since 1997 the "Assessment of human-induced soil degradation in South and South East Asia" (van Lynden/Oldeman 1997) is available. Also, geo-referenced data on agricultural, natural, and socioeconomic conditions are increasingly available, that allow for a spatially explicit analysis. These data sets come from different sources, among them data derived from satellite images

(e.g. on Land Cover), disaggregated data, that combines tabular and spatial data (Wood/Chamberlin 2003) and data spatially interpolated from individual points of measurement (e.g. precipitation data).
To sum up - while competing hypothesis on socioeconomic causes of soil degradation exist, data sources allow for analyzing the problem at a regional level. This is the aim of the following paper. The main objective is the quantification of the relations between soil degradation and socioeconomic causes under varying agricultural conditions. The specific objectives are:

- to develop a geo-referenced database on soil degradation and its potential causes for south, east and southeast Asia,
- to determine clusters with similar agricultural framework conditions,
- to identify the relationships between socioeconomic factors and soil degradation within these clusters.

The paper starts with an introduction to the analytical approach (section 2). The data used, and the steps of data integration will be explained in section 3. Empirical results from the structuring of framework conditions and relationships with water erosion will be provided in sections 4 and 5. Finally, conclusions will be drawn in section 6.

Analytical approach

In order to differentiate causal relations by profiles of agricultural conditions, this work uses the concept of "pathways of development" developed at the International Food Policy Research Institute (IFPRI) as a base for the conceptual framework: A "development pathway" is defined as a common pattern of change in farmers' livelihood strategies, associated with its causal and conditioning factors (Pender et al. 1999). Three hypotheses are drawn:

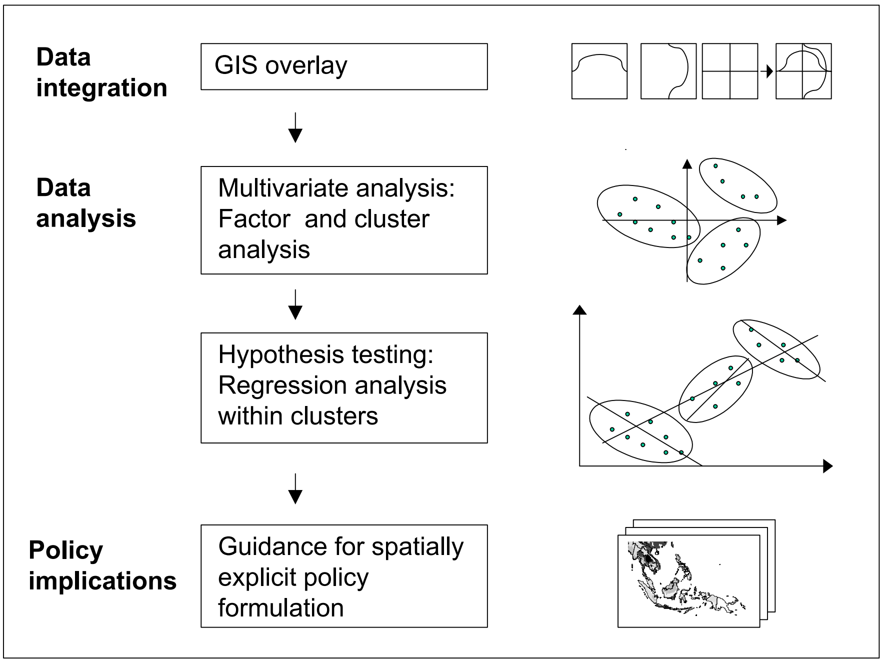
1) Agricultural development takes place worldwide due to increasing market access and population growth.

2) The process of agricultural development is neither universal nor unique. Instead, patterns can be distinguished.

3) The nature of problems in resource management is determined by agricultural development patterns, defined here as regional profiles of natural and socioeconomic conditions for agriculture, and the type and intensity of land use.

The methodological procedure is visualized in figure 1.

Figure 1: Methodological procedure



Source: own illustration

The problem of data integration will be discussed in Section 4. For data analysis, a combination of statistical methods was employed. Multivariate methods, namely factor and cluster analysis, are used to structure the data. Subsequently, hypothesis testing methods where employed to test for causes of water erosion.
Factor analysis is used to detect the structure in the relationships among variables and for data reduction. Representative variables for each factor can be selected for further analyses which are nearly independent of each other. Cluster analysis can then be used to structure objects of a heterogeneous population. Objects are grouped in homogenous subgroups based on their similarity with regard to multiple characteristics while clusters should be dissimilar to each other. The non-hierarchical K-Means cluster analysis with the SPSS-"quick cluster"-algorithm to choose the initial cluster centers is applied. The number of clusters can be determined by comparing different solutions with regard to variance explained by the cluster solution (Bacher 2001).
In order to identify the potential causes of water erosion, first an analysis of contingency tables of cluster membership with water erosion severity analyzes the relevance of the water erosion by cluster. Finally, a regression analysis is conducted to quantify causes of water erosion. Since the variable on the severity of water erosion is at ordered scale, ordered logistic regression is employed.

Data

The soil degradation data considered is the qualitative "Assessment of the Status of Human-Induced Soil Degradation in South and Southeast Asia" (ASSOD) (van Lynden/Oldeman 1997). ASSOD was a joint effort by the Food and Agriculture Organization of the United Nations (FAO), the International Soil and Reference Information Centre (ISRIC), and national soil sciences institutes in Asian countries. At ISRIC, a base map was produced, in which polygons with similar landforms where delineated. Expert assessments from collaborating national institutes where reported based on common criteria. For each polygon several types and subtypes of soil degradation could be reported together with the degree of degradation, the area affected, the direct cause of this subtype of degradation, protection measures taken and the rate of degradation. The criteria for the degree of soil degradation is the productivity decline due to soil degradation, called impact. The "impact" of soil degradation was determined from the management level (in three categories from low to high management level) and the productivity decline due to soil degradation (in five ordered categories). In a matrix this information was combined, denoting a higher impact of water erosion for equal productivity decline with higher management level. Through this, it was corrected for the measures taken to compensate the degradation-induced productivity decline, which can be assumed to be stronger in more intensive agriculture. The data reflects the average state of soils within 10-15 years prior to the assessment. The data is available as vector data with an average size of about 1000 km^2 (median) with remarkable range of size.
To represent agricultural framework conditions and potential causes of water erosion, a database was assembled from geo-referenced data sets available for Asia, shown in table 1. The database covers natural, socioeconomic and agricultural conditions. Since no single data set on poverty is available for the region, data from National Human Development Reports, holding data at second or third administrative level, was assembled. As a proxy for poverty, the score of the Human Development Index (HDI) was used. In order to make the figures comparable among countries and years, the national data was related to the HDI score for the country in the UNDP Human Development Report 1995[1]. Since for China and India data was only available at province level - which in both countries cover large areas -, national census data on literacy at district level was used for these two countries[2].

[1] It was calculated as
HDI = HDI_int_95 + ((HDI_prov - HDI_country) / HDI_country) * HDI_int_95)
where
HDI_int_95 = HDI score of the country in the UNDP Human Development Report 1995
HDI_prov = HDI score of the province or district in the National Human Development Report
HDI_country = average HDI score of the country in the National Human Development Report.
The respective national reports are listed in the references.
[2] The index for these countries was calculated as

Table 1: Variables and data sources

Variable name	Description of variable	Source	Source: Data collection and name of variable	Resolution of data
Precipitation	Average Annual Precipitation 1961-1990	FAO/IIASA (2002)	Global Agro-Ecological Zones Project (GAEZ), Plate 1	0.5°
LGP	Length of growing period (days)	FAO/IIASA (2002)	GAEZ, Plate 14	0.5°
Slope GAEZ	Median of terrain slopes derived from GTOPO30 (classes 1-7)	FAO/IIASA (2002)	GAEZ, Plate 9	0.0833°
Slope Hydro1k	Slope	U.S. Geological Survey's (USGS) EROS Data Center	HYDRO 1K Elevation Derivative Database, Slope	0.00833°
Soil fertility constraints	Soil fertility constraints (classes 1-7)	FAO/IIASA (2002)	GAEZ, Plate 22	0.0833°
Max. cereal output	Expected grid-cell output per hectare for multiple cropping of rain-fed and irrigated cereals (high level of inputs) (16 classes)	FAO/IIASA (2002)	GAEZ, Plate 54	0.0833°
Population density	Population Density (pers./km^2), 1995	Deichmann (1996)	The Asia Population Database	0.0417°
Cropland share	Croplands Dataset 1992	Ramankutty (1998)	1992 Croplands Dataset	0.0833°
Bovines density	Livestock - Bovines (animals per 100 ha) in East Asia	Dixon et al. (2001)	The Global farming Systems Study, Livestock Bovines, EaP	0.05°
Ruminants density	Livestock - Small Ruminants (animals per 100 ha) in East Asia	Dixon et al. (2001)	The Global farming Systems Study, Livestock Small Ruminants, EaP	0.05°
Cover factor	Soil cover of Land cover, classified from Seasonal Land Cover Regions, (6 categories)	a)	Eurasia Land Cover Characteristics Data Base Version 2.0, Seasonal Land Cover Regions	1 km
Mod Fournier Index	Modified Fournier Index, calculated after (FAO/IIASA 2002), based on monthly average precipitation data	Rik/Cramer (1991)	IIASA Climate Database, Mean monthly precipitation	0.5°

a) These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey's EROS Data Center http://LPDAAC.usgs.gov.
Source: own illustration

All data were integrated by a geographic overlay. Data sets were aggregated to the polygons of the ASSOD map. Since the latter had a rather poor geographic fit, rubbersheeting was undertaken, using two other maps as a reference: the Digital Soil Map of the World (FAO 1995) and the country and coastal lines from the political boundaries template of the Digital Chart of the World (taken from Deichmann (1996)). Each data set was than overlaid with the respective ASSOD map that it matched best (based on knowledge about the base map and visual tests). Due to the low quality of the ASSOD base map, and the fact that additional maps also differ in resolution and quality, the data sets were summarized by their median within one polygon of the ASSOD map[3]. Arc View Spatial Analyst was

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HDI= HDI_int_95 + ((EI_district - EI_country) / EI_country) * HDI_int_95)
where
EI = education index = Literacy rate/100
HDI_int_95 = HDI score of the country in the UNDP Human Development Report 1995
EI_district = EI score of the district calculated from census data
EI_country = average EI score of the country calculated from census data.
Data sources are the "China county level data on population and agriculture, keyed to a 1:1 M GIS map" with data from the census of 1991, and data on the literacy rate from the 1991 census in India (Office of the Registrar General, India, Census of India 2001 (Table 4: literacy rate 1991) . http://www.censusindia.net/cendata1/index2.html?pa=4.).

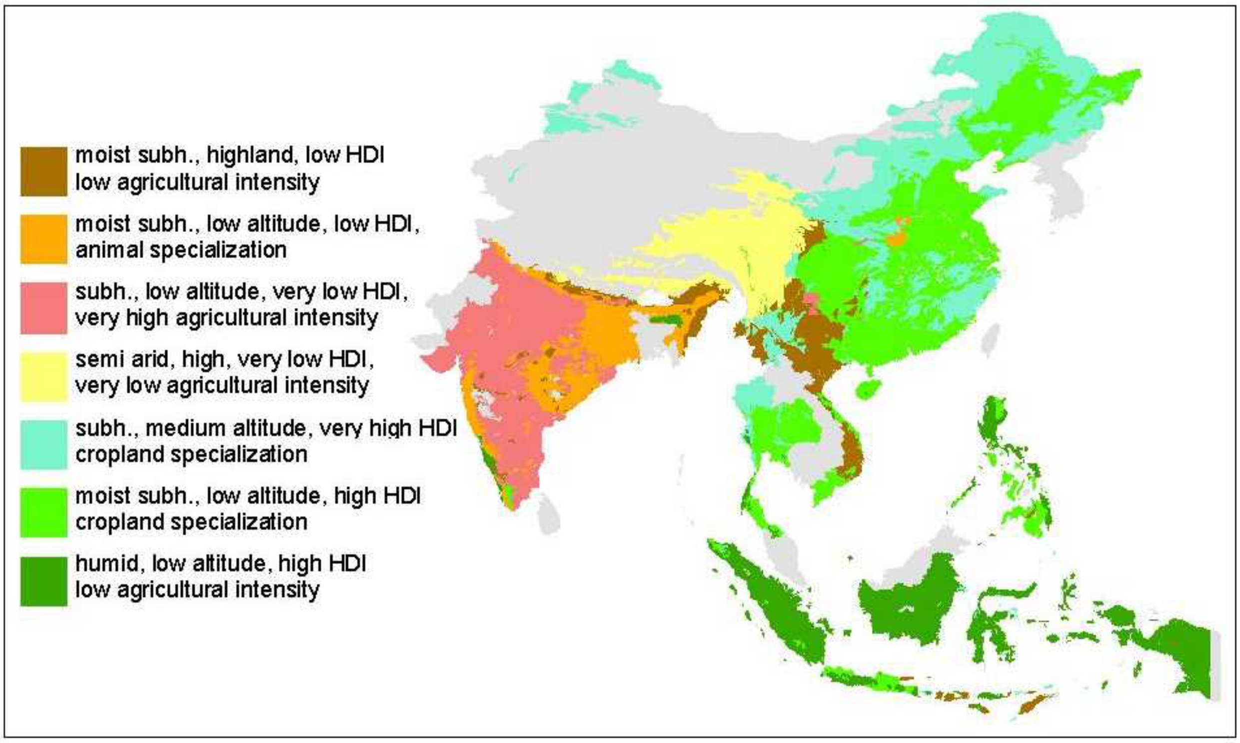
[3] Most raster maps are distributed in an unprojected version. Therefore, raster cells differ in size, depending on their geographic location. The overlay was undertaken with the unprojected maps, which can involve a bias towards raster cells

used for the overlay. Since parts of South East Asia are unsuitable for agricultural use, the sample was reduced to those polygons, that where not classified as desert, water, ice or urban according to the classification of dominant ecosystems by FAO/IIASA (2002), yielding a sample of 2779 polygons.

Identification of development clusters

For use in the cluster analysis, representative variables for each factor of a factor analysis were chosen[4]. The five representative variables are mean annual precipitation, altitude, share of cropland, bovines density and the Human development index. In order to avoid systematic influences on the clustering, objects where arranged in random order. A cluster solution with seven clusters was chosen based on three test criteria based on the explained variance (Bacher 2001). All clusters are homogenous as indicated by F-values below 1 for each variable in one cluster (i.e. the variance for one variable within the cluster divided by the variance for the whole population). Clusters can be interpreted based on the means of the unstandardized variables. Cluster labels and the geographic distribution of clusters are shown in figure 2.

Figure 2: Agricultural development clusters



Source: own illustration

The first cluster is a highland cluster with medium precipitation, a low average score of HDI, and a low agricultural intensity as indicated by both low share of cropland and low bovines density. It is located in the mountain areas of China, India, Vietnam and Nepal. It is relatively small in area, but compared to the other clusters, the number of objects is about average, since polygons with higher slopes are in average smaller than polygons of lower slopes. The second cluster is moist subhumid, with a low altitude, low HDI, and a specialization in bovines, located mainly in the coastal and north-western areas of India. The third cluster is subhumid, with low altitude, a very low HDI, and a very high agricultural intensity of both cropland and animals. It is located in the central parts of India. The fourth cluster is semi arid, with a high altitude, a very low HDI, and a very low agricultural intensity,

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within one polygon that represent a smaller area. However, since the medians were used as summaries, this bias can be neglected.

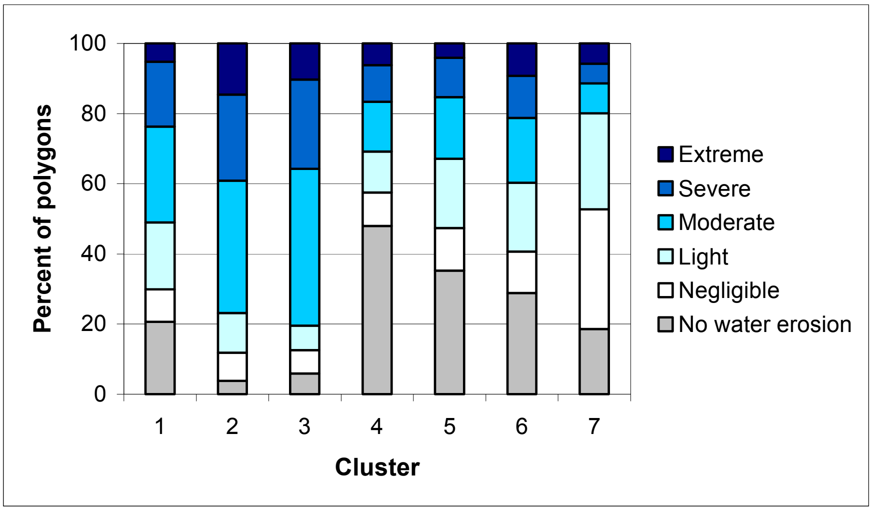
[4] The factor analysis was run on 12 variables chosen to represent agricultural development. Based on the criteria of a good simple structure and a low number of factors in order to reduce the data to the maximum possible extent, a five-factor-solution was chosen. The solution explains 84% of the total variance in the data.

located in Western China. The fifth cluster is subhumid with medium altitude, a very high HDI, and a specialization in cropland, found mostly in north eastern China, but also in parts of Thailand. The sixth cluster is moist subhumid with a low altitude, a high HDI, and a cropland specialization, found in eastern China, Thailand, the Philippines, Indonesia (Java), and southern Vietnam. The seventh cluster is humid, with a low altitude, a high HDI, and low agricultural intensity, found mainly in Indonesia, but also in the Philippines and Thailand.

Causes of water erosion

The clusters have clear differences with regard to the severity of water erosion as shown in figure 3.

Figure 3: Distribution of water erosion severity by cluster



Source: own calculations

Figure 3 displays the non-weighted shares of polygons showing the respective severity of water erosion, not the area affected. Water erosion is most severe in the second and third cluster, where up to 80% of the polygons are affected by strong or moderate erosion. Both clusters are located almost exclusively in India. In India, the reported impact classes of water erosion are generally high. It can be assumed, that differences in the perception of national soil sciences institutes partly account for the result. Severity is also very strong in cluster 1 with high altitude and low HDI. It is less of a problem in the remaining clusters 4 to 7, with weakest severity in clusters 4 and 7, the semi arid cluster and the humid cluster with low altitude and low agricultural intensity. Relevance of water erosion by cluster seems to be determined in parts by natural conditions (e.g. the cluster with high altitude and medium precipitation is affected strongly) and in parts by socioeconomic conditions (e.g. more intensively used clusters tend to be stronger affected by water erosion).

Causes of water erosion by cluster were assessed in ordered regression analyses using the SPSS procedure PLUM with the link function logit. As an indicator of water erosion, the information on extent and impact of water erosion was combined in a matrix to three ordered classes of severity of water erosion (in order to account for possible inaccuracy in the qualitative assessment as well as the mathematical requirements of ordered regression analysis, which needs a sufficient number of observations for each category). Due to the high estimates of water erosion in India, a dummy variable for India was entered in the models, for the case that India makes up a relevant share of the sample. Also a dummy variable for Indonesia was entered into model, if Indonesia is present in a cluster, since the estimates for Indonesia are not in accordance with the guidelines for ASSOD (van Lynden/Oldeman 1997). Considered as causes of water erosion are natural factors (slope and precipitation), land use (share of cropland, bovines density) and socioeconomic factors (population density, poverty). These variables appeared to be relatively independent of each other in the factor analysis. However, since different variables representing intensity of land use were correlated, two models were estimated: One model (table 2a) testing for the impact of slope, precipitation, poverty, share of cropland, and bovines density on water erosion. A second model (table 2b) analyzes the impact of population density on water erosion instead of the two variables on agricultural specialization, the other variables remaining.

Table 2a: Results of ordered regression analysis 1

Variable	Model						
	All Asia	Clu 1	Clu 2	Clu 3	Clu 5	Clu 6	Clu 7
Slope	+				+	+	
Precipitation	+			-		-	
Poverty	+	+			+	+	+
Bovines density		+			+	-	
Share cropland	+				+	-	+
Dummyvar.	+		+				
India	-					-	-
Indonesia							
R^2 (Nagelkerke)	0,15	0,11	0,23	0,11	0,17	0,14	0,23
N	2779	325	212	271	534	551	501
Parameters shown are significant at least at the 0.05 level.							

Source: own calculation

Table 2b: Results of ordered regression analysis 2

Variable	Model						
	All Asia	Clu 1	Clu 2	Clu 3	Clu 5	Clu 6	Clu 7
Slope	+				+	+	
Precipitation	+			-		-	
Poverty	+	+			+	+	+
Population density	+			+	+	+	+
Dummyvar.	+		+				
India	-						-
Indonesia							
R^2 (Nagelkerke)	0,18	0,10	0,23	0,15	0,21	0,12	0,22
N	2779	325	212	271	534	551	501
Parameters shown are significant at least at the 0.05 level.							

Source: own calculations

Tables 2a and 2b display the signs of the parameter estimates for each model. In the first column, results for the whole sample are shown, in the following columns, the results by cluster are shown. Cluster 4 is not considered further, since water erosion is less of a problem in the semi arid cluster. Overall, the relevance of the models is low as indicated by low values of the Pseudo R^2 calculated after Nagelkerke only between 0.10 and 0.20. The explanation is unsatisfactory for cluster 2 in both models and cluster 3 in the first model, where only a dummy variable for India has a significant parameter estimate. Not all models meet the parallelism assumption, partly due to complexity of the models. This calls for further analysis on the functional form and on criteria for the selection of variables. However, results are quite stable, if using linear regression analysis instead, and are in accordance with the bivariate correlation among water erosion and explanatory variables.
The variables slope, precipitation, and poverty, which are entered in both models (table 2a and 2b), show the same signs and significance of impacts in both models. In table 2a, the impact of agricultural intensity along with slope, precipitation, and poverty is shown. For all of Asia, slope, precipitation, poverty, and the share of cropland, as well as the dummy variable for India show a significant positive impact on water erosion. The slope variable carries the expected positive sign in

clusters 5 to 7 (both in table 2a and 2b), but is not significant in cluster 1 with the highest altitude, where it would also be expected to be of strong importance. Precipitation has a significant negative impact in two clusters (both in table 2a and 2b), which is somewhat surprising. An explanation may be, that this variable is likely to represent rather agricultural suitability than erosivity of rainfall, which could lead to the interpretation, that more marginal areas in these clusters are affected stronger. Results for the variables on intensity of land use are less clear. The density of bovines has a positive impact in two clusters, but not for Asia as a whole. For cluster 6, 7 and all Asia, the parameter of this variable was estimated separately for Indonesia and the rest, since for the latter no geo-referenced data on the bovines density is available. The impact of the share of cropland is positive for all Asia, but negative in one cluster, indicating the problem of water erosion being more severe in more marginal areas in this cluster. Poverty shows a significant positive impact on water erosion for all Asia, as well as in several clusters, but not so in the two Indian clusters (both in table 2a and 2b). In table 2b, the impact of population density along with slope, precipitation, and poverty is shown. For all of Asia, slope, poverty, and population density, and the dummy variable for India show a significant positive impact on water erosion. The results for the latter are the same in significance and sign as in table 2a. Population density shows a positive impact in all but two clusters. These are the two clusters located mainly in India, where the overall population density is high. It must be noted, that population density is not related to carrying capacity, which is only corrected for partly through clustering of homogenous groups of agricultural conditions.
Overall, it can be noted, that for the socioeconomic variables poverty and population density, results confirm the assumption of the importance of socioeconomic factors for soil degradation. Although the relevance differs by cluster, the distinction by cluster does not reveal opposed signs of the parameter estimates for these variables. If significant, population density and poverty show a positive impact on water erosion.

Conclusions

Secondary data was used in order to empirically assess the long discussed question of the impact of socioeconomic factors and land use on soil degradation. The regional level of analysis allows for generalizations over different Asian countries, while using spatial information well below the national level. The analytical framework used elaborates on this advantage of large n and observations with diverse conditions, testing the links between socioeconomic and land use factors with soil degradation under differing agricultural framework conditions.
Although results must be interpreted with caution due to the rather low fit of the models, the following generalizations can be made. The relevance of water erosion differs by agricultural development cluster. It is determined in parts by natural conditions, e.g. it is strong in the highland cluster, but is not limited to marginal areas. Instead, water erosion is also of relevance in the densely populated clusters that are less erosion prone due to natural conditions. The impacts of socioeconomic factors on soil degradation differ by cluster, but at this aggregated level the direction of the impact remains the same, with a positive sign for the estimates of poverty and population density. Results for land use are differing, indicating to the relevance of agricultural suitability.
Major policy implications of these findings are, that the focus on poverty alleviation and policies to reduce pressure on the land should be pursued. If taken seriously, poverty alleviation could benefit both the poor and the environment.

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