Spatial associations between household and community livelihood capitals in rural territories: an example from the Mahanadi Delta, India

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Abstract

Despite the increasing interest of the Sustainable Livelihood Framework in the field of international development and in academia and the recent call for the use of mixed-methods approach, there has been little analysis that bring together qualitative and quantitative methods over a large geographical extent. Based on findings from the rapid rural appraisals during which participants identified the key assets needed to achieve their livelihoods, this chapter tries to bridge this research gap by differentiating two levels of livelihood capitals (household capitals and community capitals) and creating quantitative indicators that can be mapped across the delta, derived from national census data and satellite sensor data. Spatial patterns and differentials in access to livelihood capitals across the delta are examined and the associations that exist between household capitals, between community capitals, and between both are quantified. The results suggest that household physical capital is positively associated with household financial and social capitals but negatively associated with household human capital, supporting the hypothesis that households trade part of their workforce to increase their income, exemplified by the dynamics of male migration. A strong negative association between access to village amenities and access to natural resources was also clearly supported by the findings. Moreover, proximity to main axes of communication increases access to village amenities but decreases access to natural resources, while remoteness increases household human capitals but decreases household physical and financial capitals. Overall, this paper demonstrates that there are associations between livelihood capitals and that they are spatially clustered.

Keywords: spatial livelihoods, community capitals, household capitals, participatory, rural development, India

Highlights

- We observed spatial variability in common-pool resources and private assets affecting livelihoods in rural India.
- Workforce availability increases with remoteness, while both household physical and financial capital increase with proximity to urban areas.
- Households make trade-offs between different assets to meet their needs and mediate vulnerabilities.
- Access to natural capital and to community infrastructures are negatively associated spatially.
- We advocate for the separation of community capitals from household livelihood capitals to characterise rural livelihoods.

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1. Introduction

Livelihood opportunities available to rural households in low and middle income countries are highly dependent on their access to capitals both at the household and community levels, which contributes to their resilience to social, economic and environmental stresses (Chambers & Conway, 1991; Ellis, 2000). While livelihood perspectives have provided a holistic approach to understand the systems in which rural poverty exists, they have been criticised for ignoring important power relations (Mclean, 2015), for focusing mainly on material wellbeing and for not considering the range of motivations for livelihoods decision (Carr, 2013). Moreover, their lack of operationalisation at multiple spatial scales (Reed et al., 2013) has limited the explanatory power of the Sustainable Livelihoods Framework, as it does not account for the issues of spatial access to public services that have emerged in current debates on rural development (Flora et al., 2015). The Sustainable Livelihoods Framework only considers household-level assets and capabilities defined as livelihood capitals, such as land, workforce, financial capital, productive equipment, social resources, skills and aptitudes (Scoones, 2015). However, community-level assets, such as environmental conditions (elevation, rainfall, soil quality), distance to natural resources (forest, wetlands) and distance to services (markets, hospitals) are a significant component of rural livelihoods and poverty (Iiyama et al., 2008; Kim et al., 2016; Palmer-Jones & Sen, 2006) and are thought to have an influence on households' choice of a set of livelihood activities (Barrett et al., 2006; Okwi et al., 2007). Although Lindenberg (2002) also mentioned the importance of differentiating community capitals from household capitals, the livelihood studies that have dealt with community-level assets focused only on common-pool resources (Hahn et al., 2009; Erenstein et al., 2010; Donohue & Biggs, 2015). Moreover, a key point of criticism has been the propensity for single metrics analyses based on a data-driven selection of indicators, making quantitative livelihood studies another multidimensional poverty index approach (Scoones, 2015). In this study, local knowledge is used to identify household and community capitals that are relevant and robust for examining the susceptibility of households to landless agricultural labour, which is an indicator of chronic poverty.

Different components are included in the Sustainable Livelihoods Framework, in particular livelihood capitals, a term that encompasses both assets and households' capabilities. However, despite the recommendations from previous poverty studies (Farrow et al., 2005; Okwi et al., 2007; Kim et al., 2016) and from livelihood studies (Smith et al., 2001; Kristjanson et al., 2009;

Angelsen et al., 2011) that have consistently shown the importance of multi-level approaches to rural poverty, there has been very few livelihood studies that have taken such a multi-level perspective, differentiating common-pool resources from households' private assets. Until now, the majority of studies seeking to apply the Sustainable Livelihoods Framework have mainly focused either on household-level capitals (e.g. Fang et al., 2014), on aggregated proxies of community capitals at the district or provincial level (e.g. Donohue & Biggs, 2015) or have conflated both household and community capitals together (e.g. Paudel Khatiwada et al., 2017). This paper argues that common-pool resources (community capitals) should be differentiated from private assets (household capitals) as they operate under different dynamics of decision-making, management, ownership and control. The findings from a Participatory Rural Appraisals conducted in rural India confirm this hypothesis by revealing that although access to common-pool resources can be mitigated by social relations of class and caste, rural dwellers perceive village amenities as determinant for their livelihood opportunities, but differentiate them from their own private assets. Participants differentiated them from their own private assets, since the availability of one community capital can create synergies amongst households from the same community, which can have a positive or negative effect over the quantity and the possibilities of their private capitals and livelihood opportunities.

Access to each livelihood asset is flexible and individuals can make trade-offs between different assets to meet their needs and mediate vulnerabilities (De Haan, 2012; Morse & McNamara, 2013). For example, Parizeau (2015) showed that informal recyclers' households in Buenos Aires (Argentina) make trade-offs between education and immediate income by bringing children to the streets. For these households, developing their human capital often requires trade-offs with other assets, in particular with their labour. Farrington et al. (1999) also argued that households flexibly combine different capitals and make trade-offs between them to achieve their livelihood strategy. Considering the potential vulnerabilities involved in the use of livelihood assets and the need for trade-offs caused by leveraging them has to be considered to understand the sustainability of these assets (De Haan, 2012). Such an analysis, however, needs to take into account how the broader geographical, social and economic dimensions of vulnerability can impact the availability of these assets. Two mechanisms may lead to synergies and trade-offs among livelihood capitals (Rodríguez et al., 2006): (i) one household capital is intensified by a particular community capital, as in the case of proximity to schools acting as a catalyst of people's skills and capabilities

on the long-term, providing education to individual members of the community; (ii) individuals (or communities) make trade-offs between different capitals to meet their needs and mediate vulnerabilities, as in the case of financial capital that might be invested into means of production; and (iii) a given external factor may affect several capitals at the same time as with the impact of a cyclone negatively influencing common-pool natural resources and also decreasing households' protective assets. As a result of these associations, some livelihood capitals might co-vary positively, for instance community productive infrastructures may improve household financial capital by increasing their access to banks and to markets, while some livelihood capitals may co-vary negatively, as for productive infrastructures might be degrading common-pool natural resources through the expansion of the built environment. Planning strategies aiming at enhancing the economic development of a particular region need to account for such linkages to make sure that investments in one capital do not lead to the depletion of several interrelated capitals.

The Mahanadi Delta located within the state of Odisha in East India (Figure 1), is one of the populous deltas where environmental stressors have adversely impacted livelihood opportunities, exacerbating poverty levels and driving households into chronic poverty (Chhotray & Few, 2012; Das, 2012; Dhamija & Bhide, 2013). The delta covers a coastline of 200 km and is exposed to chronic floods during the monsoon due to the low volumetric capacity of the Mahanadi, Brahmani and Baitarani rivers (Syvitski, 2008). Its location on the North Indian Ocean tropical cyclone track leads to a high likelihood of cyclones to make landfall on the area both before and after the monsoon period (Chhotray & Few, 2012). Most households are dependent on subsistence rainfed rice agriculture for their incomes and staple food production, which is highly sensitive to weather-related events, such as droughts and floods. As a consequence, the Mahanadi Delta is one of the poorest regions in India with one of the lowest rates of economic growth and a high prevalence of poverty (World Bank, 2008). In the delta, 46.8% of the population live below the poverty line, of which 90% are subsistence farmers who practice sharecropping on marginal lands, with a very low productivity (Hedger & Singha, 2010). Most of them are marginal and smallholder farmers who have very low income from their land; they represent 60% of the total number of rural households in the delta. The problem of rural poverty in the Mahanadi Delta has been compounded by high population density (623 inhabitants per square kilometre) and recurrent environmental disasters including cyclones, erosion, storm surges, floods and droughts (Bahinipati, 2014; Ericson et al., 2006; Syvitski, 2008), resulting in the loss of agricultural land, intensification of farming

systems and persistent crop failures (Dixon et al., 2001; Savath et al., 2014). As a consequence, understanding the spatial distribution of livelihood capitals and the potential trade-offs emerging between them allows us to understand better the spatial determinants of rural poverty, which is of relevance to tackle the wider issues of sustainable development in rural areas of developing countries in general and in the Mahanadi Delta in particular.

Despite the increasing interest in spatial analyses of poverty and livelihood issues in the field of international development, there has been little analysis that brings together qualitative and quantitative methods over a large geographical extent to map livelihood assets and characterise their associations. Understanding the spatial patterns of asset endowment and how they might be associated with each others should not be overlooked as it provides a multidimensional and coherent approach to improving households access to livelihood assets, which are seen as the main determinants of household-level risk-management capacity (Jakobsen, 2013). This paper aims to integrate findings from a participatory analysis conducted in the Mahanadi Delta in India into a quantitative analysis to highlight the spatial distribution of livelihood capitals and to characterise the existing associations between them. More specifically, this paper answers this objective by addressing the following sub-objectives: (i) to build a quantitative indicator-based conceptualisation of livelihood capitals at both community and household levels; (ii) to examine spatial patterns and differentials in access to livelihood capitals across the Mahanadi Delta; and (iii) to characterise the associations between household capitals, between community capitals, and between both. By doing so, this paper advocates for the separation of community capitals from household livelihood capitals to characterise rural livelihoods and presents a methodology to quantify the Sustainable Livelihoods Framework at the village-level based on results from participatory rural appraisals. Finally, it demonstrates that livelihood capitals are spatially clustered in the landscape and there are spatial trade-offs between them.

2. Materials and methods

This section presents the materials and methods used to quantify the findings from the Participatory Rural Appraisal during which participants identified the key assets needed to achieve their livelihoods. It presents how quantitative indicators for both household and community capitals were created by using national census data and satellite sensor data.

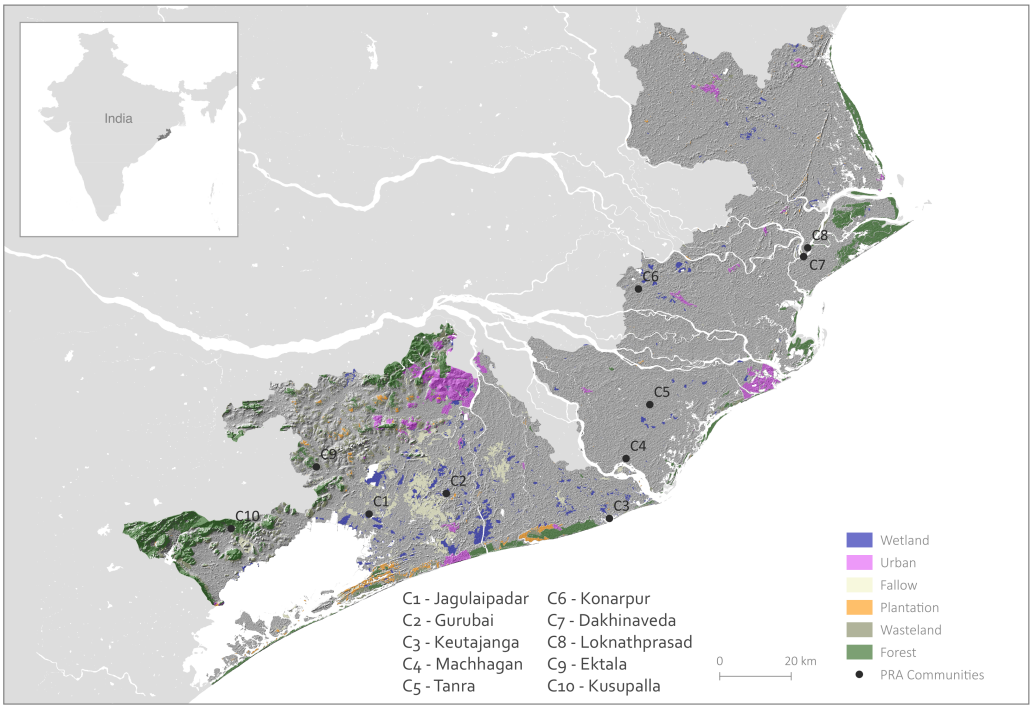

Figure 1: Study site and sampled villages. Participatory Rural Appraisals was conducted in ten villages, selected according to their level of vulnerability, their location and the dominant land cover.

2.1. Participatory Rural Appraisal to identify local perceptions

In-depth fieldwork was conducted to characterise the relative importance of household and community capitals, to explore livelihood dynamics and to draw up a profile of livelihood systems. This was also used to identify indicators that stakeholders, experts and local residents perceive as representative and robust to examine the effects of each capital on livelihood opportunities. A Participatory Rural Appraisal was used as the principal suite of tools for data collection to highlight the perceptions and opinions of rural dwellers. This suite of tools enables local people to share their knowledge, and discuss and analyse their situation using their own terms (Mukherjee, 2005). Literature evidence highlights the hierarchical social complexity of class, caste and gender in India, which are reflected in both men and women's roles and participation in the labour market, including engagement in agricultural activities (Ray-Bennett, 2009; Savath et al., 2014). In this regard, fieldwork activities were undertaken separately for men and women (Leduc, 2009; Cornwall, 2003).

Fieldwork, conducted between February and May 2016, consisted of two phases. First, semi-structured interviews (see Appendix 1, for the interview guide) were conducted with governmental and non-governmental organisations at the State level to obtain: (i) a deeper understanding of the organisations working in the area and of their activities; (ii) a map and typology of the livelihood zones and an understanding of the main livelihood strategies in each zone; and (iii) an understanding of the main external shocks faced by rural households. Several Participatory Rural Appraisal tools were used in ten villages across five districts to represent the heterogeneity of cases across the Mahanadi Delta (Figure 1). Districts were selected according to their level of vulnerability (Nathan et al., 2008) and their location, so as to cover the whole geographical extent of the delta. Villages were then sampled based on their socio-economic characteristics (using census data provided by the Registrar General and Census Commissioner, 2011) and on the main livelihood activities conducted by households (based on the key informant interviews). The activities were conducted over 4 to 5 days in each village.

The social, economical and political status in India relies upon a class-based structure with landlords at the top and landless labourers at the bottom (Kannabiran & Kannabiran, 1991; Kapadia, 1998). Inequalities are perpetuated by the system of castes (Ray-Bennett, 2009), which is "an essential ingredient in the study of stratification patterns in Indias population" (Deshpande, 2001). These power relationships were acknowledged and taken into account throughout the Participatory Rural Appraisal to give the opportunity to all social classes to express their opinion. Focus groups were purposely held separately, one with men (led by a local man) and one with women (led by a local woman), to enable women who suffer from a lack of recognition in India to have their say (Cornwall, 2003; Deshpande, 2002; Leduc, 2009). Moreover, focus groups with non-dominant castes were held separately in multi-caste villages (C1, C2, C6) to enable people from lower castes to express their opinions and issues. Following Chambers (1994); FAO & ILO (2009); Wang & Burris (1997), different activities were used to cross-check the data acquired and to cover all the aspects of livelihood systems: (i) resource mapping; (ii) social mapping, (iii) seasonal calendar; (iv) wealth ranking; and (v) impact chain of external shocks and stresses (see Appendix 2 for the focus groups guides used during the PRAs). During the first part of the participatory workshop held as a focus group, general information about the village and the evolution of its infrastructure were discussed. Differences within the village regarding livelihood assets and strategies were investigated. Once the different categories were identified by the participants,

they quantified the proportion of households falling into each category. The last activity was a participatory photography workshop using the photovoice methodology (Blackman, 2007; Wang & Burris, 1997) on the theme of "Key assets to achieve your livelihoods"; a theme broad enough to let the participants themselves highlight the different roles that community and household capitals play in their decision to pursue a livelihood strategy.

2.2. Data used for the quantification of livelihood capitals

Several sources of data were needed to proxy the different capitals highlighted by participants during the Participatory Rural Appraisal, such as demographic data, infrastructure and amenities and environmental data. Census and satellite remote sensing data were chosen as they are publicly accessible online, they are available at a fine resolution (village-level or finer) and cover a large spatial extent.

The demographic data used in this paper were a subset of the 2011 Census of India and included all rural villages located within the five districts (Bhadrak, Jagatsinghpur, Kendrapara, Khorda and Puri) located within 5-meter contour of the Mahanadi river delta (9,829 villages in total) (Registrar General and Census Commissioner, 2011). The data are at the village-level and consist of three sets of tables: "village amenities", "house-listing" and "population enumeration". The "village amenities" dataset includes area in hectares, total income, total expenditure and the different infrastructures available related to education, medical, drinking water, communication, banking, recreational and cultural facilities, accessibility to the village, power supply and natural resources. The "population enumeration" tables provide comprehensive information on the population, with all the information recorded based on the twelve months preceding census enumeration. For instance, these tables provide figures about the main livelihood activity of each individual (cultivator, agricultural labourer, entrepreneur, other) and its frequency ("main" for more than six months per year, "marginal" for less than six months per year). Given that villages are statutory units in India with a definite boundary and separate land records, the administrative boundaries provided by the Office of the Registrar General & Census Commissioner of India were used.

The use of environmental data has a relatively long tradition within rural development studies due to the fact that rural livelihoods and land use are intertwined (Santiphop et al., 2012; Watmough et al., 2013; Nguyen et al., 2017). The Geographic Information System QGIS was used

to extract different environmental conditions at the village-level and to compute euclidian distances to closest resources. Our calculations cover an area extending 100 km beyond the administrative boundary of the study area to avoid edge effects. Land cover data was used to estimate proxies for environmental conditions. GlobeLand30 data (30 m resolution for 2010) (Chen et al., 2014) and Bhuvan data (25 m resolution for 2011) (NRSC, 2006, 2012) were harmonised using the method developed by Vancutsem et al. (2013) to get a coherent land cover dataset for 2011. The main features extracted from this dataset are built-up (urban/rural), forest cover (evergreen/deciduous/shrubs/mangroves), agricultural land (cropland/plantation/fallow), wasteland, wetland and waterbodies. Detailed maps of water-logged areas (seasonal and permanent), erosion process and salinity intrusion for 2008 - 2009 were also used to evaluate environmental stresses (Ministry of Rural Development, 2011).

2.3. Quantification of livelihood capitals

During the Participatory Rural Appraisal, participants identified the factors that influence their choice of a livelihood activity. Proxy variables from the secondary data available described previously were selected to represent the factors identified by the participants. The variables were then assigned to livelihood capitals (natural, physical, human, financial, social) according to the type of good they fall into: private goods being classified as household capitals and common-pool resources as community capitals. Given the high number of variables falling under each type of capital and their collinearity, extraction methods were used to reduce the information to a lower dimensionality space. Principal Component Analysis was used to decrease the amount of redundant information by de-correlating the input vectors, as suggested by Filmer & Scott (2012). Although Filmer & Pritchett (2001) has recommended to use PCA when continuous variables are used and factor analysis when there are both continuous and categorical variables, the weightings for categorical variables derived from factor analysis and PCA are usually very similar (Howe et al., 2008; Watmough et al., 2016). Moreover, PCA has often been used in cases when continuous and categorical variables are used in combination, as it is easier to run and interpret (Howe et al., 2008). It was decided not to combine multiple factors as it would have distorted what the component captured and would have made it difficult to interpret (McKenzie, 2005). The first step consisted in normalising the data stored as a matrix (X) into $\overline{X}$. Then, the eigenvectors (U) and eigenvalues (Λ) of the covariance matrix (C) were calculated using Singular Value Decomposition. Finally, to

reduce the dimensionality, the data was projected onto the largest eigenvectors $P = U^T \cdot \overline{X}$. The first eigenvector was kept and checked how the component captured the initial variables. The new vector was kept only if, for each variable, the loading's direction matched the findings from the Participatory Rural Appraisal. The index for each capital was then computed by weighting each variable using its factor loading and then summing them.

2.3.1. Household capitals

Private assets were grouped together and classified as household livelihood capitals (Table 1).

Table 1: List of variables used for the quantification of household livelihood capitals. The associated factor loading retrieved from the PCA represents the weight of each variable in the construction of the household livelihood capitals.

Category	Variables	Source	Product	Type	Factor
Natural capital					
Rainfed cropland	Non-irrigated area sown per household	Census	VA	Continuous	0.539
Irrigated cropland	Irrigated area sown per household	Census	VA	Continuous	0.255
Tree plantation	Area of tree crops per household	Census	VA	Continuous	0.664
Pasture	Area of pasture per household	Census	VA	Continuous	0.785
Physical capital					
Means of transportation	Proportion of households with access to bicyle	Census	HL	Continuous	0.824
	Proportion of households with access to motorcycle	Census	HL	Continuous	0.744
Electricity	Proportion of household with no access to electricity	Census	HL	Continuous	-0.708
Human capital					
Dependency ratio	Ratio of dependent individuals (inactive) per active person	Census	HL	Continuous	-0.667
Illiteracy	Ratio of illiterate individuals per capita	Census	PE	Continuous	-0.735
Men workforce	Ratio of men in age of working per household	Census	PE	Continuous	0.396
Financial capital					
Financial services	Ratio of households with access to financial services	Census	HL	Continuous	0.722
Protective assets	Proportion of households without asset ownership	Census	HL	Continuous	-0.777
Housing conditions	Proportion of households with "Dilapidated" houses	Census	HL	Continuous	-0.530
Social capital					
Communication	Proportion of households owning telephone	Census	HL	Continuous	0.718
Castes	Ratio of Scheduled Castes and Tribes	Census	PE	Continuous	-0.718
Marital status	Proportion of households with no married couples	Census	HL	Continuous	-0.456

Measuring household natural capital.. A common view amongst participants was that the amount of agricultural land (rainfed and irrigated cropland, tree plantation) available to one household influences their potential income and food, and they considered them as determining factors for their choice of a livelihood activity. Participants in inland villages (C2, C5 and C6) argued that the area of pasture available per household was also a key determinant of employment, as it enabled them to develop livestock rearing as a diversification strategy. The four highest loadings of the eigenvector from the Principal Component Analysis represent these capitals highlighted by participants as determinants for the choice of their livelihood strategy: cropland area per cultiva-

tor ($\lambda_{\text{rainfed}} = 0.54$, $\lambda_{\text{irrigated}} = 0.26$), area of pasture per household ($\lambda_{\text{pasture}} = 0.79$) and area of tree plantation per cultivator ($\lambda_{\text{orchards}} = 0.66$). Overall, the first factor loading from the PCA accounted for 67% of the variance in households' access to natural capital and villages which scored high on the first factor were those where households had a greater access to household natural capital.

Measuring household physical capital.. A number of factors falling under household physical capital were identified by participants as determinant in their choice of a livelihood strategy. First, private access to electricity enables households to conduct their livelihood activity by operating agricultural pumps and machinery ($\lambda_{\text{no\_electricity}} = -0.71$). Means of transportation ($\lambda_{\text{bicycle}} = 0.82$, $\lambda_{\text{motorcycle}} = 0.74$) also came up during the rapid rural appraisals, since they allow households to look for new outlets for their production or for livelihood opportunities and increase their access to nearby services (hospitals, banks, schools) through the reduction of travel times. The eigenvector kept from the PCA accounted for 54% of the variance in household physical capital.

Measuring household human capital.. A recurrent household human capital that was identified by participants as influencing their choice of a livelihood strategy was the number of active members in the household ($\lambda_{\text{dependencyratio}} = -0.67$). A high dependency ratio limits the range of activities that one household can put in place. Male workforce was a recurrent asset that came up during focus groups ($\lambda_{\text{men\_workforce}} = 0.40$), men being in charge of looking for income-generating activities in the Indian social context. Finally, level of education and individual skillsets surfaced in most focus groups. Participants argued that educated members were a strength for one household because they "did not suffer from unemployment". Based on existing literature about poverty (e.g. Watmough et al., 2016), levels of female illiteracy were used as a negative proxy for this asset ($\lambda_{\text{illiteracy}} = -0.74$). Overall, the eigenvector kept for household human capital accounted for 53% of the variance in household human capital between villages.

Measuring household financial capital.. One of the proxies used to quantify household financial capital are households' access to financial services for savings and credits ($\lambda_{\text{financial\_services}} = 0.72$). This indicator only captures financial inclusion as defined in the census: only households with access to banking services provided by nationalised banks, private banks, foreign banks and cooperative banks are considered to have access to financial services. However, many smallholder

farmers –particularly households from lower castes and the poor– lack access to formal credit and are forced to rely on semi-formal (credit and thrift societies, self-help groups, primary agricultural credit societies) or informal (moneylenders and shopkeepers) sources. Moreover, access to such financial services can become a negative asset when the debt-to-capital ratio is greater than one. Although the unavailability of data to capture such dynamics weakens the explanatory power of this indicator for financial capital, the inclusion of protective assets that are held as a store of value and that can be sold if the household faces an external shock ($\lambda_{\text{no assets}} = -0.78$) enables to proxy households' dependency on informal credit when trying to meet unforeseen expenditure. Participants also identified housing as a measure of the financial capital available to one household, as it is associated with access to financial services. Based on census variables, housing condition was used as a proxy to represent such an asset ($\lambda_{\text{dilapidated}} = -0.53$). The eigenvector kept for household financial capital accounted for 54% of the variance in household financial capital between villages.

Measuring household social capital.. Household social capital is about the value of social networks, including bonding with norms of reciprocity. Although not identified clearly as a capital, it emerged from the focus groups that marriage is one of the most important kinship encountered at the household level in rural settings, and so one of the pillar of social capital. Households' marital status was used to represent such kinships ($\lambda_{\text{married\_0}} = -0.46$). Evidence from the literature and from participants shows that members from lower castes (scheduled caste and tribes) suffer from social and economic exclusion, from a lack of access to certain types of assets and even from a social unacceptability to undertake some activities. As a consequence, the ratio of SC and ST was considered as a negative proxy for social capital ($\lambda_{\text{caste}} = -0.72$). Finally, participants mentioned that households who owned a mobile phone had stronger social networks, especially outside the village, enabling them to have access to alternative livelihood opportunities ($\lambda_{\text{telephone}} = 0.72$). Overall, the household social capital eigenvector accounted for 41% of the variance in household social capital between villages.

2.3.2. Community capitals

After reviewing the determinants of households' livelihood strategies identified by the participants, public and common-pool assets were grouped together and classified as community livelihood capitals (Table 2).

Table 2: List of variables used for the quantification of community livelihood capitals. The associated factor loading retrieved from the PCA represents the weight of each variable in the construction of the community livelihood capitals.

Category	Variables	Source	Product	Type	Factor
Natural capital					
Cropland	Total area of potential cropland in 2010	GL30/Bhuvan	LC	Continuous	0.722
Forest	Total area of forest in 2010	GL30/Bhuvan	LC	Continuous	0.670
Agricultural pressure	Ratio of sown area per unit of potential farmland for 2010	Census/GL30	Authors	Continuous	-0.202
Physical capital					
Power supply	Availability of electricity for agriculture	Census	VA	Dummy	0.351
Accessibility	Distance to nearest concrete road	Census	Authors	Continuous	-0.809
Outlets	Distance to nearest market	Census	Authors	Continuous	-0.642
Human capital					
Medical facilities	Distance to nearest medical facility	Census	Authors	Continuous	-0.842
Educational facilities	Distance to nearest secondary school	Census	Authors	Continuous	-0.847
Water facilities	Distance to nearest drinkable water source	Census	Authors	Continuous	-0.166
Financial capital					
Formal financial institutions	Distance to nearest commercial banks ATM	Census	Authors	Continuous	-0.998
	Distance to nearest cooperative bank	Census	Authors	Continuous	-0.998
Poverty schemes implementation	Distance to nearest public distribution system shop (PDS)	Census	Authors	Continuous	-0.134
Social capital					
Community services	Distance to nearest ASHA	Census	Authors	Continuous	-0.678
	Distance to nearest community centre	Census	Authors	Continuous	-0.615
Recreational facilities	Distance to nearest sports field	Census	Authors	Dummy	-0.677
Women's group facilities	Distance to nearest SHG	Census	Authors	Continuous	-0.691

Measuring community natural capital.. Participants, in particular those from remote villages, argued that the total amount of land in the village was a driver of agricultural livelihoods, as it would increase opportunities for agricultural labour and agricultural marketing. A greater area of cultivated area in the village enables the creation of a supply force that can attract traders to come, as it was the case in the village C10 where an increase in the number of breeding goats households had attracted traders to come, thus creating new livelihood opportunities, such as goat broker. Households who were engaged in non-agricultural activities also argued that the greater the total surface of agricultural land in the village, the more economic activities and livelihood opportunities there are. As a consequence, the area of potential cropland was considered as a positive community capital and included in the quantification of its indicator ($\lambda_{\text{crops}} = 0.72$). Forest resources were unanimously raised by participants as a common-pool capital in villages located near forests. Different products from the forest can be traded, such as timber (wood, charcoal) and non-timber forest products (bamboo, sal seeds, kendu leaves and mahuwa flowers), enabling households to diversify their incomes. As the availability of products in a forest is correlated with its size, such a resource were proxied by the total area of forest accessible to the village, computed from satellite imagery ($\lambda_{\text{forest}} = 0.67$). A number of issues undermining community natural capital in the long-

term were also raised by participants, such as the area of land that is left fallow for regeneration ($\lambda_{\text{pressure}} = -0.20$) . Such an area is used by households to diversify their agricultural system: as one participant said about his photo during the *photovoice* activity, "I use non-agricultural land to dry my harvest and other households use it for cow dung preparation". Overall, the eigenvector kept accounted for 48% of the variance in community natural capital between villages.

Measuring community physical capital.. The importance of community physical capital to influence the choice of a livelihood strategy recurred throughout the focus groups. Having access to all-weather transportation infrastructures ($\lambda_{\text{road\_dist}} = -0.81$) was perceived as a factor that improves working opportunities through access to marketing outlets (traders are able to come to buy goods directly in the village). Although households benefit differently from such assets depending on their wealth and social networks, proximity to a marketing outlet and availability was mentioned as key determinants to develop income-generating activities ($\lambda_{\text{outlet}} = -0.64$). A marketing outlet could be of different types, from general (such as a market) to more specific (such as a cooperative or society), proximity to an outlet acting as a catalyst for activity diversification, such as milk or raw-fish production. Finally, the availability of power supply for agricultural activities in the village ($\lambda_{\text{electricity\_agri}} = 0.35$) is a positive community asset enabling households to invest in other means of production (e.g. pumps) without having to buy costly power generators. The eigenvector kept accounted for 56% of the variance in community physical capital between villages.

Measuring community human capital.. A number of themes falling under community human capital emerged from the focus groups. Participants argued that proximity to medical, educational and water village amenities would enhance their labour capacity. Availability of education in the premise of the village recurred throughout the discussions, especially during focus groups held with women. They argued that access to schools would enable their children to spend their day there, giving them time for other activities and increasing their future livelihood opportunities. Education scores were computed from the census using Euclidian distance to nearest secondary school ($\lambda_{\text{school}} = -0.85$). Another recurrent theme was the issue of distance to health facilities ($\lambda_{\text{medical}} = -0.84$) and the availability of water infrastructures ($\lambda_{\text{drinkable}} = -0.17$). According to them, a better access to health facilities and to safe water infrastructures would diminish the risk of health problems. Overall, the factor kept for community human capital accounted for 53% of the variance between villages.

Measuring community financial capital.. Proximity to a bank was raised as critical when it comes to state schemes and pensions: for example households needed a bank account in order to get paid for work they conducted under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA). As a consequence, infrastructures linked to formal financial services were included, such as the distance to the nearest commercial bank ($\lambda_{\text{bank}} = -0.99$) or cooperative banks ($\lambda_{\text{coop}} = -0.99$). Two other types of infrastructures specific to the Odisha context were flagged by participants: the distance to Public Distribution System Shops ($\lambda_{\text{PDS}} = -0.13$), which are shops distributing rations at a subsidised price to the poor. Although PDS are not a financial institution, it was decided to include this variable in the community financial capital because they are a policy financial tool for poverty reduction. The eigenvector kept accounted for 62% of the variance in community financial capital between villages.

Measuring community social capital.. Community social capital emerged discretely from the focus groups, as the concept of social networks at a village-level was not identified by participants. However, participants mentioned the importance of social groups such as self-help groups ($\lambda_{\text{SHG}} = -0.69$), youth and farmers groups to give them new income opportunities or to increase their migration options. These groups are considered as community-level assets, which enhance social networking that might lead to alternative livelihood opportunities. Participants, and especially women, showed a strong interest in SHGs, which is a way for them to build strong social links and to build their capacities and empower themselves. It also emerged from the discussion that availability of recreation facilities, such as public spaces ($\lambda_{\text{ASHA}} = -0.68$, $\lambda_{\text{comcentre}} = -0.62$) or sport fields ($\lambda_{\text{sportfield}} = -0.68$) was an important community capital that enabled to build strong kinships and that also prevented younger males to migrate out of the village for work. Overall, the factor kept accounted for 55% of the variance in community social capital between villages.

2.4. Quantifying trade-offs between livelihood capitals

The term "trade-off" has been widely used in the literature to analyse different types of compromises between ecosystem services, such as ecological (e.g. Vihervaara et al., 2010), temporal (e.g. Koch et al., 2009), planning (e.g. White et al., 2012) or between beneficiaries (e.g. Martín-López et al., 2012). The first classification was developed for the Millennium Ecosystem Assessment (2005) and grouped ecosystem services trade-offs into four categories (Rodríguez et al., 2006):

(i) trade-offs in space, defined as the spatial lag between production and delivery of a service; (ii) trade-offs in time, defined as the temporal lag in the delivery of a service; (iii) reversibility of ecosystem services, defined as the resilience of a service after a disturbance in its production; and (iv) trade-offs across ecosystem services, defined as the positive or negative effects of the supply of one service on the supply of other services.

To guide the assessment of ecosystem services trade-offs, Mouchet et al. (2014) combined the previous classifications into a new methodological framework by accounting for both ecological and socio-economic aspects of ecosystem services trade-offs. The authors also presented an overview of the quantitative methods available for analysing ecosystem services trade-offs and gave examples of corresponding hypotheses to be tested. To answer the objective of this paper, which was to characterise which livelihood capitals are negatively or positively associated with each others, it was decided to apply this framework to livelihood capitals, although initially built for ecosystem services. Mouchet et al. (2014) argued that the best methods to test such hypotheses were multivariate analyses, when considering more than two services. Moreover, as the indicators built for each livelihood capital were quantitative variables, Principal Component Analysis was chosen as ordinal method for the analysis (Raudsepp-Hearne et al., 2010; Maes et al., 2012; Smart et al., 2010).

3. Results

3.1. Spatial distribution of livelihood capitals

Autocorrelation analysis showed that all livelihood capitals at both community and household levels, except for community natural and human capitals, were spatially clumped on the landscape rather than randomly distributed ($p < 0.01$, Figures 2 & 3). Although similarities were found among the spatial patterns of different livelihood capitals (household physical, household human, community physical), most capitals showed distinct individual spatial patterns.

The coastal part of the delta showed lower levels of both household and community natural capitals than the rest of the delta, highlighting that despite their access to the sea, issues of land degradation and coastal erosion prevent households to access such resources. Villages located near urban areas had a lower access to community natural capital, which shows that urbanisation decreases the overall availability of natural resources. However, household natural capital seemed

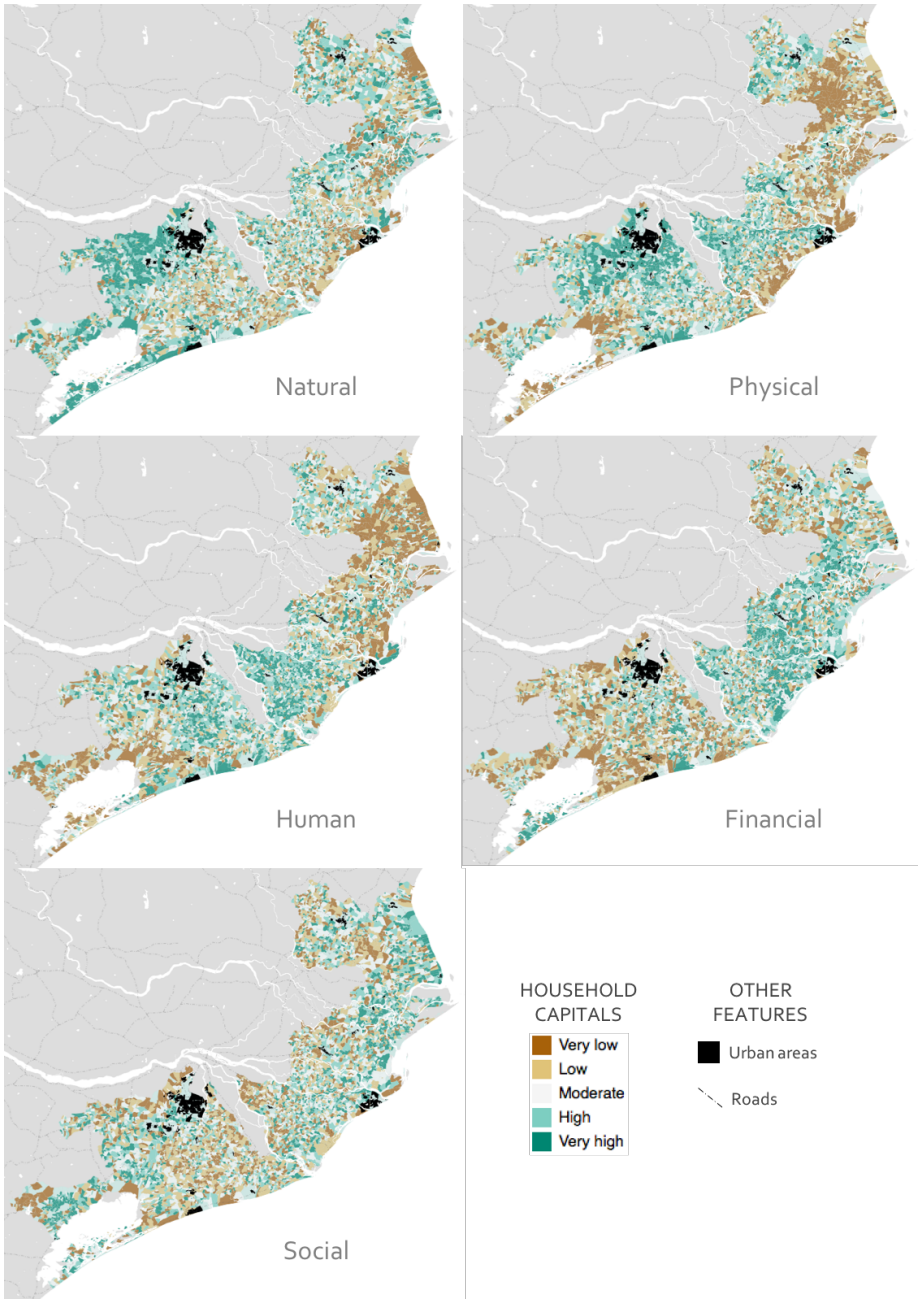

Figure 2: Spatial distribution of household capitals in the Mahanadi Delta. Villages were ranked into quintiles based on how they scored for each livelihood capital, from very low (brown) to very high (green).

to be greater in villages close to the main urban centres. The increased pressure on farm holdings due to the proximity to urban areas leads to the cornering of natural resources by few large-scale farmers, thus increasing the indicator for household natural capital.

Although physical and financial capitals (at both community and household levels) were lower in the north eastern part of the delta and in coastal villages, including fishing villages located around the Chilika Lake, it can be seen that access to financial capital at the household level is not associated with access to financial or productive infrastructures. Actually, villages located in the western part of the delta have a lower access to household financial capital than those located in the central part of the delta, despite having a greater access to banks and economic infrastructures. This interesting finding can be explained by lower scores for household social capital in these villages, highlighting households' social exclusion from financial services despite their proximity to financial infrastructures.

Forest-dependent villages, found in the western part of the delta, had a relatively greater access to natural and human household capitals compared to other villages, but a lower access to financial, physical and social capitals (at both community and household levels). Regarding community capitals, these results can be explained by the remoteness of these areas and their access to large patches of forest, thus increasing access to natural resources but also reducing access to economic and social infrastructures. Regarding household capitals, the low ranking of these villages in social household capital reveals a high prevalence of scheduled tribes who suffer from social and economic exclusion, thus explaining the lower levels of financial and physical household capital. Interestingly, these villages have greater scores of household human capital. This result, somewhat counterintuitive, highlights the large human workforce prevailing in tribal villages, whose livelihoods are based on the large amount of natural resources available.

3.2. Associations between livelihood capitals

PCA was used for the analysis of associations between livelihood capitals for both community and household levels (Figure 4). The first two components respectively accounted for 52.5% of the total variation in household capitals and 62.3% of the total variation in community capitals. At the household level (Figure 4, top), the first principal component accounted for 31.3% of the variation and represented a negative association between access to physical, financial and social capitals on one side and natural capital on the other. The second component accounted for an additional

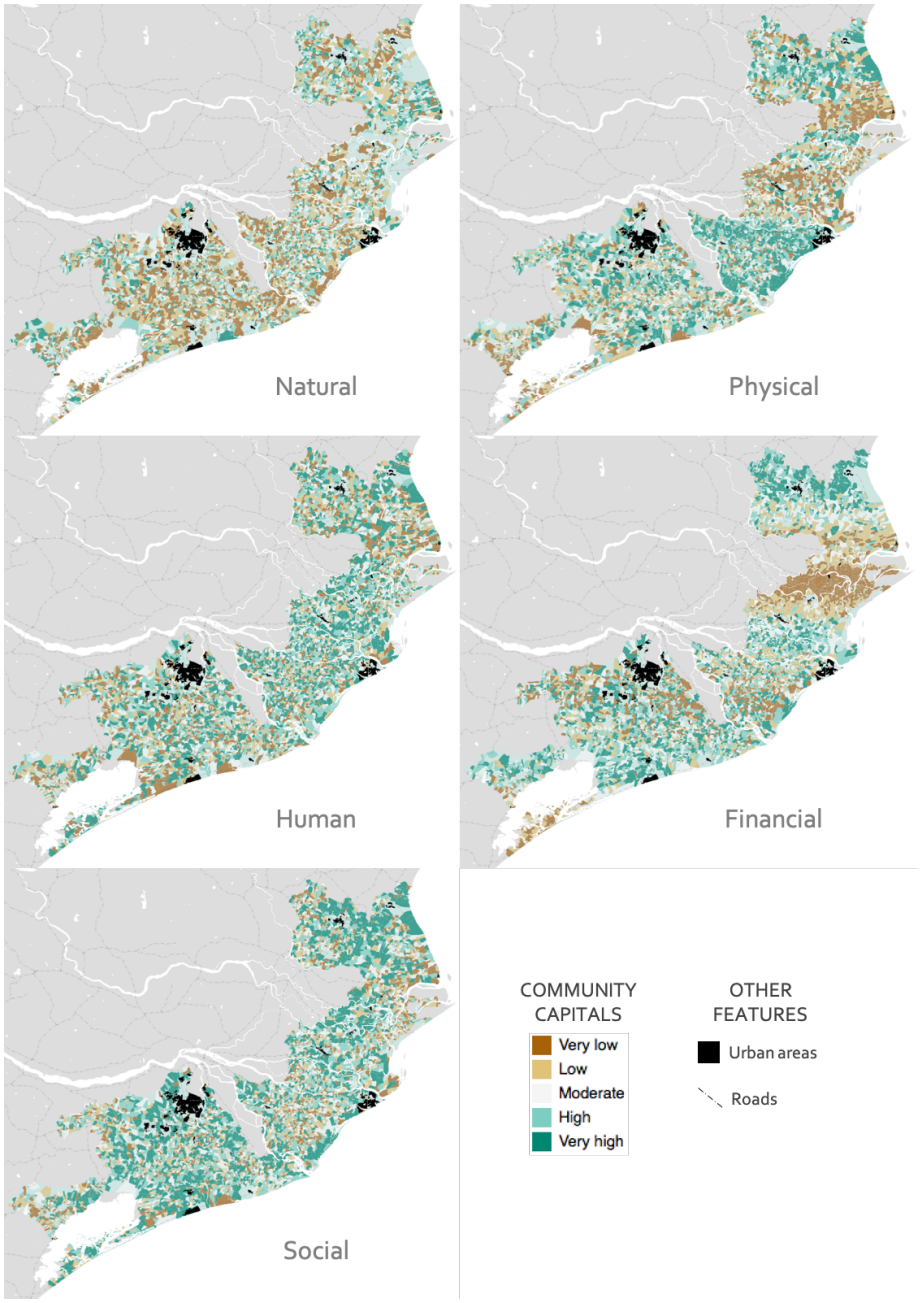

Figure 3: Spatial distribution of community capitals in the Mahanadi Delta. Villages were ranked into quintiles based on how they scored for each livelihood capital, from very low (brown) to very high (green).

21.1% and primarily described the segregation of households based on their access to human assets. At the community level (Figure 4, bottom), the first principal component showed a negative association between access to natural resources on the one side and access to economic and social infrastructures on the other. This component accounted for 40.9% of the total variation in community capitals, while the second component accounted for 21.4% and primarily described a trade-off between social services on the one side and access to healthcare and economic infrastructures on the other.

A PCA was also computed on all livelihood capitals together, irrespective of their level of analysis (Figure 5). The first two components accounted for 36.5% of the total variation in livelihood capitals. The first principal component accounted for 20.8% of the variation and represented a negative association between access to natural resources (at both community and household levels) and village amenities. The second component accounted for an additional 20.8% and primarily described the segregation of household capitals, with natural capital negatively associated with the rest of household-level assets, apart from human capital.

4. Discussion

This paper presented methods for differentiating household from community capitals, identified patterns in their spatial distribution and analysed their interactions. It provided empirical evidence of spatial negative associations at the household level between access to physical, financial and social capitals on the one side and access to natural capital on the other. It also highlighted trade-offs between access to natural resources and access to productive infrastructures at the community level.

4.1. Spatial patterns of livelihood capitals

Overall, the findings show that there is a spatial gradient of the distribution of livelihood capitals based on proximity to the main trading axes (map PC1, Figure 5). Proximity to main trading-centres or main roads increases households' access to village amenities but decreases their access to natural resources. The second spatial gradient (map PC2, Figure 5) shows that remoteness increases household natural and human capitals but decreases household physical and financial capitals. In other terms, although proximity to trading centres and village amenities is associated with an increase in households' access to productive (physical) and protective (financial) assets, it

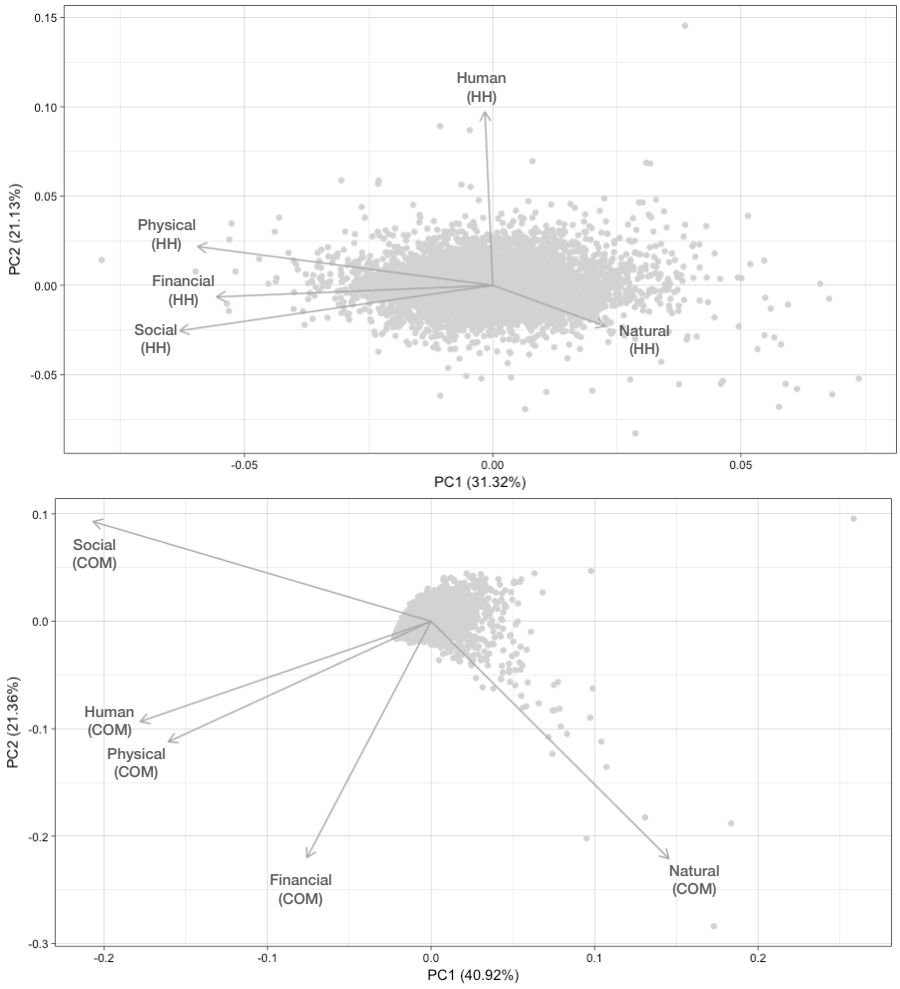

Figure 4: Eigenvectors from the PCA on household capitals (top) and on community capitals (bottom). The first component of the PCA on household capitals represents a negative association between natural resources and access to physical, financial and social capitals. The second component represents access to human capital. The first component of the PCA on community capitals represents a negative association between natural resources and socio-economic amenities. The second component represents a negative associations between social amenities and productive resources.

is most of the time accompanied by a loss in labour force (human) and in natural capital for the household. It can thus be suggested that opportunities created by the proximity to trading centres and an increased access to financial services is likely to be associated with migration, resulting in a temporary or permanent loss of human capital. Moreover, the lower levels of household natural

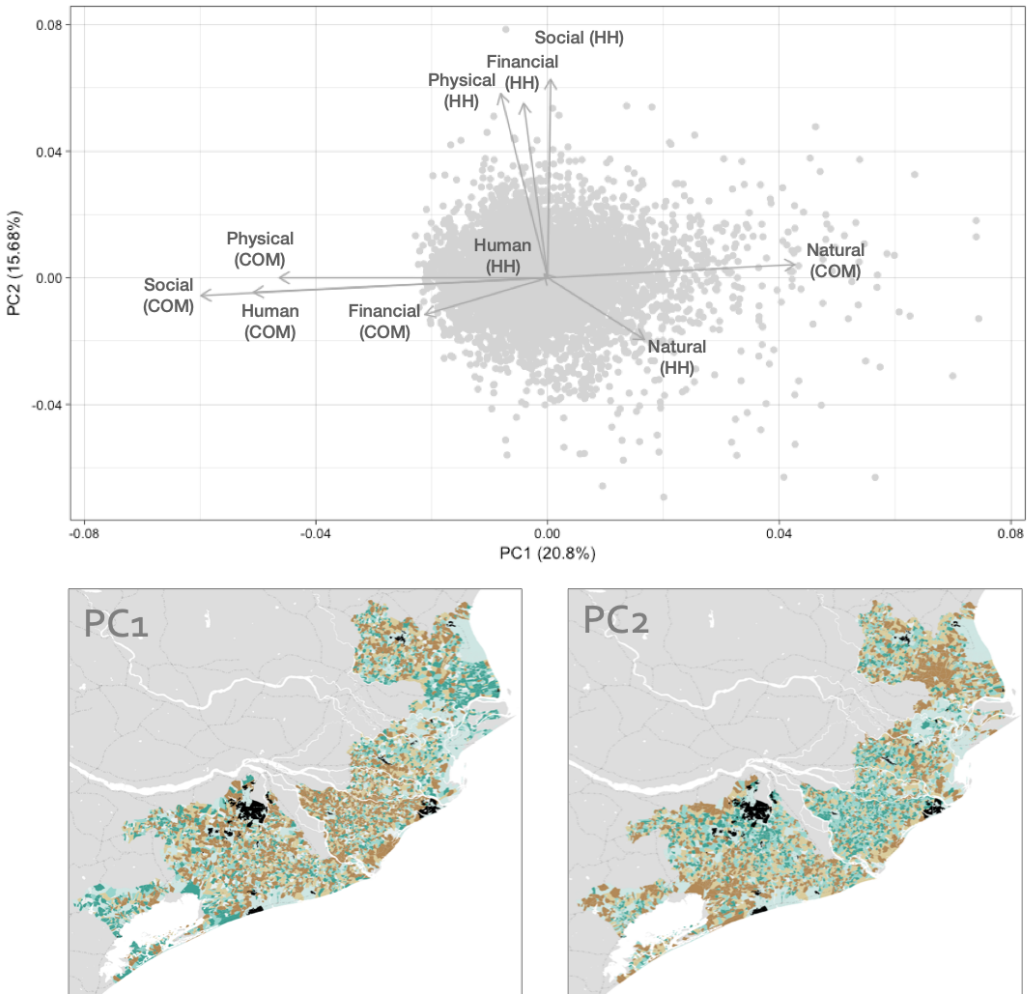

Figure 5: Eigenvectors and spatial distribution of the first two components of the PCA on both household and community capitals. The first component (PC1) represents a trade-off between access to natural resources (green) and access to productive infrastructures (brown). The second component (PC2) represents a negative association between access to natural capital at the household level on the one side (brown) and access to physical, social and financial capitals on the other side (green).

capital in these areas illustrate that proximity to trading centres and access to financial services is likely to be associated with dynamics of land-grabbing, resulting in a temporary or permanent loss of household natural capital, thus pushing households into precarious forms of employment and distress migration (van den Berg, 2010; Manjunatha et al., 2013).

The findings for household natural capital corroborate the results of Gumma et al. (2014) who presented a new land cover classification accounting for the different types of agricultural systems found in the delta. Notably, villages with low natural capital are clustered in the central part of the delta and seem to be associated with irrigated triple cropping, while villages with high natural capital are located near forested areas, where mixed agricultural systems are prevailing. These results are likely to be related to how the indicator for natural capital is built, in which only farm size is taken into account and not production. Irrigated farms where three crops per year are grown require more labour per surface unit, thus these farms are smaller on average (Directorate of Agriculture & Food Production Odisha, 2014), which leads to lower scores of natural capital (but greater scores of physical capital). On the contrary, mixed-agricultural systems are more extensive and require bigger farms for a similar production, leading to higher scores of household natural capital.

Although the signal for community physical capital is weaker than the one for household physical capital, their spatial distribution present similar patterns, with lower scores in coastal villages and in the north-eastern part of the delta. Villages located in these remote areas do not have access to irrigation facilities and have a limited access to electricity and to markets. This result echoes the findings of Chhotray & Few (2012); Bahinipati (2014) who highlighted the remoteness of these areas and that households lacked access to physical amenities, partly as a consequence of natural hazards such as the Odisha super-cyclone in 1999.

The distribution of the community human capital suggests that there is a relative homogeneous access to primary health facilities across the delta. However, households located in the south-western and north-eastern parts of the delta have a lower access to human capital. These findings mirror the findings from DECCMA (2017), which showed that the districts of Kendrapara and Bhadrak had the highest levels of male migration. Rural-urban male migration leads to an increase in the number of left-behind wives and to a decrease in households' labour force, thus leads to households with a lower human capital (Agasty & Author, 2014; Velan & Mohanty, 2015; Parida, 2016).

Similarly to the spatial distribution of villages with a low household physical capital, villages with a low household financial capital are located in the coastal fringe and in the north-eastern part of the delta. This is mainly due to the lack of ownership of protective equipment and the high number of "dilapidated houses" stemming from the impact of natural hazards. Contrary to

expectations, the findings show that community financial capital is not directly linked to accessibility, which can be explained by the omnipresence of Primary Agricultural Credit Society in agricultural villages, even in the most remote areas (Kamath et al., 2010). However, the presence of financial institutions within a village does not guarantee households to have access to financial services (Imai et al., 2010), as demonstrated by their perpendicular eigenvectors (Figure 5).

The spatial distribution of community social capital shows that this indicator is associated with accessibility, which is consistent with the absence of recreational facilities in remote villages. On the other hand, household social capital is mostly driven by the proportion of scheduled castes and tribes, located mainly near natural areas such as forests (south-west and near the mangroves in the north-east) and open water (near the Chilika lake and along the coastline), which corroborates the finding of De Haan & Dubey (2005).

4.2. Trade-offs between livelihood capitals

Altogether, the findings highlighted three distinct types of synergies between livelihood capitals and two main trade-offs (Figure 5). Physical, social and human capitals are positively associated at the community level, which corroborates the fact that village amenities are usually grouped together and located in large or medium-size towns. These associations also demonstrate a trade-off between access to village amenities on the one side and access to natural resources on the other, which supports previous research on ecosystem services in Canada (Raudsepp-Hearne et al., 2010), Denmark (Turner et al., 2014) and Sweden (Queiroz et al., 2015). Access to such community capitals creates synergies amongst dwellers that can have a positive or negative effect over their access to household capitals and over their livelihood opportunities, regardless of the social relation of caste and class at stake within a village.

At the household level, the findings show that physical capital is positively associated with financial and social capitals. This finding reflects the participants' views, who argued that wealthy households who own means of transportation would also own protective assets, would invest in their house and would have a better access to financial services. Moreover, participants also mentioned that non-married households (widowed, divorced, single) and households from scheduled castes would very rarely own productive or protective assets because of the social barriers they face, which corroborates the synergies between social capital and both financial and physical capitals found in the present paper. In other terms, higher classes of Indian peasantry are locked

into an upward spiral of wealth and power, letting the lower classes of peasantry underdeveloped (Corbridge & Harriss, 2013). This bundle is negatively associated with household natural capital, which represents households' access to agricultural land. This trade-off represents a proxy of coping dynamics: poor households sell part of their land (natural capital) to cope with shocks and increase their income (financial capital), which is then invested in their physical capital, as observed by Parida (2016).

Interestingly, we did not find any associations between household human capital, which represents one household's workforce, education and its dependency ratio, and the other household capitals. Based on the fieldwork, it seems possible that the two following processes explain this finding. On the one hand, households trade part of their workforce (human capital) through migration to increase their income (financial capital in the form of remittances), which is then invested in their physical capital, illustrating the dynamics of migration. On the other hand, higher levels of education enable households to engage in more remunerative strategies (Diniz et al., 2013), thus increasing their financial and physical capitals. These two underlying processes cancel each other, thus explaining the absence of synergies and trade-offs between human capital and the four other household capitals.

4.3. Policy relevance

From a policy perspective, this paper argues that planning should take into account synergies and trade-offs between livelihood capitals, especially regarding the potential interactions between community and household capitals. The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) that aims to guarantee the "right to work" by providing employment to the rural poor of marginalised communities seems to be well targeted to integrate both types of capitals for a sustainable rural development (Panchayati Raj Department, 2015). The type of work provided by the programme aims to create durable assets and improve community infrastructures through labour-intensive tasks such as the construction of roads, dams, canals, ponds or other water-harvesting infrastructures to mitigate drought. The MGNREGA has an influence on two components of livelihood systems: (i) on community capitals by leading to the creation of durable village amenities and infrastructures; and (ii) on livelihood activities by ensuring households to have access to 100 days of wage labour. In the light of this paper, we argue that the MGNREGA should include a spatially-explicit approach to provide place-specific infrastructure development

and activities to strengthen livelihoods of the rural poor.

In villages located near the main trading centres, agricultural tenancy laws should be implemented and enforced to regulate rents and offer security of tenure to tenants, as this paper demonstrated that the trade-off between proximity to urban areas and natural capital illustrates smallholders' land dispossession by agro-industries and large farm-holders, thus driving these households into chronic poverty (Ambagudia, 2010; Sahu & Dash, 2011). In parallel, employment activities should focus on strengthening household human capital (skills) to ensure that households are able to adapt their livelihoods to off-farm strategies. In remote villages, while there is a need to focus on the development of social and economic infrastructures, the MGNREGA should also invest in the protection and in the collective management of community natural capital (forests, lakes, communal grazing lands), on which most dwellers rely for their livelihoods. Finally, it is clear that systems of power through gender and castes play a determining role in shaping access to capitals, thus in perpetuating poverty. While this paper argues that location and access to common-pool resources also condition livelihood opportunities and might mediate or enhance the determinants of precarious livelihoods, it is clear that reducing social barriers to access capitals remains a priority and should be integrated throughout the stages of policy planning.

5. Conclusion

This paper presented an innovative way of integrating findings from participatory fieldwork with national census and environmental data to characterise associations between livelihood capitals. More specifically, it demonstrated the need to separate community capitals from household livelihood capitals to characterise rural livelihoods. This paper also gives new insights on the distribution of livelihood capitals across the landscape by quantifying their spatial associations. The existence of trade-offs between access to village amenities on the one side and access to natural resources on the other was clearly supported by the findings. Moreover, the results demonstrate that household physical capital is positively associated with household financial and social capitals but negatively associated with household natural capital, supporting the hypothesis that households trade their natural assets to cope with shocks. It was also shown that proximity to main axes of communication increases access to village amenities but decreases access to natural resources, while remoteness increases household human capital but decreases household physical and financial capitals. Although this research adds to the understanding of the question of scale regarding

rural livelihoods, the relationships between community development and livelihood dynamics are not yet sufficiently accounted for in rural development studies. Cross-scale studies looking at the dynamics of rural livelihoods in relation to community development could act as a bridge between policy programmes (often targeted at the community level) and the expected outcomes (often targeted at the household level).

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