Exploring geospatial methods of detecting rural vitality, vulnerability and versatility in rural regions in Bavaria

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SUMMARY

Rural regions in Bavaria are under stress in emerging global crises and, in the face of rapid changes and uncertainties, they require strategies to enhance their resilience. With the aim to develop such strategies, 3VRUT was formed as a consortium of partners from Germany, Japan, Poland and Spain in charge of developing a methodology to evaluate, quantify, and classify the vulnerability, versatility and vitality (the 3Vs) in selected eight rural towns. Two of the selected case studies, Bayerisch Eisenstein and Obermichelbach-Tuchenbach, are located in the German federal state of Bavaria, and represent a shrinking village and a resilient village respectively. To this stage, the methodology is being traced and calibrated with a pilot case study. Thus, the aim of this paper is to: 1) describe the development of a set of indicators for the 3Vs assessment, and 2) show the results of the first stages of the research, including the first impressions of the field visits to the two Bavarian case studies. The 3VRUT indicators to assess the vulnerability, versatility and vitality of the selected rural towns comprise the dimensions of the natural environment (29 indicators), infrastructure and the built environment (26 indicators), institutional framework (16 indicators), social relationships (14 indicators), and economic structure (26 indicators). With the purpose to observe and detect variations in the 3Vs, the set of indicators was developed through an interdisciplinary approach that connects the socio-economic and geospatial dimensions of remote sensing data, geostatistics, field observations and surveys for data collection, analysis and interpretation. With this in mind, the combination of remote sensing technologies with machine learning and Artificial Intelligence technologies, we will be able to spot and predict changes in socio-economic behavior and opportunities in the rural setting.

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1. INTRODUCTION

The land surveying community has a strong interest and professional history in measuring and understanding how both urban and rural regions develop. The measurements tend to focus however on physical and spatial developments. Photogrammetry and remote sensing help to detect changes in the physical environment by observing and classifying changes in objects, built-up areas, land use, infrastructure constructions, natural habitats and water availability amongst others. Monitoring such changes regularly supports informed decision making and smart land management as the data can generate scenarios and predictions of how and where the physical environment expands, changes characteristics and develops new features. The benefit of using these technologies is that patterns in observations and measurements can be automated and extrapolated to larger areas, such that one can make informed decisions over larger areas. As such it helps to solve problems at larger scales and connections of smaller scales to larger scales.

Monitoring socio-spatial changes remains only partly possible, and often depends on indirect measurements rather than direct measurements. Direct measurements of the growth of informal settlements, often at the outskirts of larger cities and sometimes also in the inner parts of the cities, indicate a social change related to informality for example. It is however not the direct measurement through aerial photos and satellite images which see the social nature of tenure. Instead, one has to infer from socio-economic surveys that structures which through ground trothing appear to be held in an informal manner that similar structures may also be held in an informal manner. Land rights, such as ownership or user rights or public and private restrictions are even more difficult to see if they are not aligned with physical features. Indeed, fences and walls may indicate boundaries of plots, but they may not be directly usually as evidence in a cadastral system if there is no connection to any form of validation on the ground. Even more complex is the measurement and automation of development or variations in forms of development. Measuring vitality could be one of those indicators of development, and may be crucial to derive the spatial inequality between urban and rural regions. Yet, how does one measure vitality at larger scales and which spatial proxies in relation to physical changes could be constructed to highlight and detect changes and patterns of vitality. This is the key question of this research.

Before starting the process of creating automated detecting and validation mechanisms there are two things to determine first. The first issue is to understand the concept of vitality and how it relates to similar concepts, such as versatility, vulnerability and resilience. Social and geographic sciences have a broad literature base employing these concepts, yet do not yet systematically rely on remote sensing. The second issue is how remote sensing literature currently looks at the issues of vitality, vulnerability, versatility and resilience through researching patterns in physical objects. The question hereby is if and how one can use this knowledge and extend this by adding certain logics and proxies which connect the changes to physical spaces to socio-spatial and development spaces. This paper provides the first efforts of this research by reviewing first these two questions and by exploring in two rural villages in Bavaria, Germany which features on the ground are exemplary of vitality, vulnerability, versatility and resilience. The ultimate goal of this first step is to develop an assessment framework (which we refer to 3VRUT framework in the remainder of this paper) for each of the aspects on a larger (i.e. state, national or global) scale, which can support strategies of sustainable and responsible land management and spatial development.

The reason to focus on Bavaria is twofold. The first reason is historical and pragmatic. There were already close links to the Bavarian agencies of rural development which had already been relying on a framework of measuring vitality in rural villages. Although not all villages utilise this framework and although the framework is not connecting to any remote sensing data the insights can be used to support the development of our 3VRUT framework. The second reason is more spatial information oriented. For Bavaria there are many spatial dataset available and accessible, which could make it useful for a development and testing of methodology. The research in Bavaria is part of an international project where multiple case studies will be compared, namely in Japan, Poland and Spain. This international comparison and validation should serve to test and revise the assessment methodology within difficult socio-spatial and institutional contexts.

2. THEORY AND FRAMEWORKS SO FAR

The concepts and indicators of vitality, versatility, vulnerability and resilience are existing in various knowledge fields and epistemologies. Vitality in rural regions is not necessarily related to agro- economic incentives (Mack et al. 2018). In the context of rural development (de Vries 2018) posits that vital villages are those where there is a high degree of self-consciousness of the villagers, there is a sense of pride in the village, villagers have a positive image about their village, there is some form of local and regional identity, people engage in local activities and citizens activate and are activated. Cultural and educational activities contribute furthermore to vitality of rural areas (Lehtonen 2021). Similarly, vulnerability has multiple aspects and dimensions, such as social, economic, historical, and political ones, which function all at multiple scales. (Thomas et al. 2019) call therefore for a dynamic social approach to vulnerability, as ‘vulnerability is a multidimensional process rather than an unchanging state’.

As all of the 3VRUT components do not relate to universal definitions across these, the concepts are to a large extent disciplinary boundary objects. Given our research aim to use these concepts indeed across disciplines we had to create our own assessment framework to make the concepts operational. The development of the rural resilient assessment matrix relied on several consecutive discussions and derived a framework with 5 categories of 3VRUT indicators: economic, environmental, infrastructure and built environment, institutional and social. For each of these categories it is possible to specify a number of dimensions and their relevance for vitality, vulnerability, versatility and resilience. In particular the environmental and infrastructure and built environment indicators are directly visible through remote sensing, but for the social, economic and institutional indicators these derivation is less obvious.

Several studies derive information about rural vitality, vulnerability, versatility and resilience using geospatial datasets. Some methods for extracting information from spatio-temporal data sets include land use (LU) and land cover classification, spatial modelling, statistical analysis like regression, indexing. For instance, from LU classification the presence of agricultural fields is an indicator of land ownership which can be identified as a factor of versatility. Measurement of settlement density such as high density as in indicator of vitality in the town. Similarly, accessibility to roads, hospitals, schools is an indicator of versatility and vitality. Sentinel-1 (S-1) and Sentinel-2 (S-2) data; various optical indicators of clay content Short-Wave Infrared (SWIR) bands and soil indices) were tested over bare soils. Satellite moisture products, derived from combined S-1 and S-2 data, were also tested as an indicator of soil texture. Algorithms based on the support vector machine (SVM) and random forest (RF) methods are proposed for the classification and mapping of clay content and a three-fold cross-validation is used to evaluate both approaches (Bousbih et al. 2019). Rough texture of bare soil to examine the soil productivity in the region is an indicator of vulnerability. Population density, Complexity of LU (both values given in literature, see source), Area per capita (calculate w/ LU map) distance to public facilities, distance to public transportation, distance to green areas (all 3 w/ distance calculations in GIS - Data from openStreetMap) (Smilka 2020). Compactness as an indicator of liveability and practicability of a town/city is an indicator of vitality. In another study LU classification from high-res orthophotos is compared to cadastre (parcel sizes). Measuring size of the building within the compound as a measure of poverty in lower and middle income countries (Watmough et al. 2019). This can be a proxy to measure indicators to study the presence of vulnerability. Extracting information from LU maps to study the proportion of woodland or grassland in buffer zone around settlement (between highway etc.) , which is also a measurement of isolation (Watmough et al. 2019) as an indicator of presence of vulnerability and a measure of vitality as it also provides access to ecosystem services. Classification of LU according to Local Climate Zones (LCZs) (sparsely built, compact mid-rise, open-high-rise, bare soil, water connect it to prior determined socioeconomic characteristics w/ VSURF (Variable Selection Using Random Forests). Measures the shape complexity of the LCZ class (Sapena et al. 2021). Indicating intensity of factors as Health, Housing, Education, Income, Affordability, Employment, Transportation, and Commuting within a spatial dimension as an indicator of compactness. This measure can be used as a proxy to identify the presence of vitality in the town. LU Maps used to evaluate bare soils within city boundaries (outside of agricultural boundaries) to calculate proportion of land left vacant (Banister et al. 1997). Connects urban form to socio-economic indicators. It can be used as a proxy measure of vitality. Based on the concept that a street is central if it is included in many of the shortest paths linking pairs of nodes (street intersections) in a street network as a measure of accessibility. Fusion of high-res panchromatic imagery and low-res RGB imagery to get high-res multispectral image. The data was used to derive social classes. Surroundings location are described (within a predefined buffer zone) of every pixel to make social classification easier using 7-dimensional buffer was then used as input for neural network that can then calculate social status of every pixel according to its surroundings (gardens, garages, pools) (Tapiador et al.

2011). Presence of gardens as an indicator of vitality in the town. Modelling the impact of the urban spatial structure on the choice of residential location using binary mask derived from Terra SAR-X and Tan DEM-X satellites representing urban areas at a geometric resolution of 12m (Kong et al. 2007; Wurm et al. 2019). This can be a measure of versatility in the town. The Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) collects global low-light imaging data intensity of nocturnal light emission as sensed by VIIRS instrument mounted on Suomi-NPP at a geometric resolution of 750 m (Elvidge et al. 2017). Important feature of DNB data is the detection of electric lighting from human settlements. This can be used as a measure to identify the presence of vitality by monitoring human activity. As a measurement of biodiversity NDVI, EVI (Enhanced Vegetation Index), surface reflectance, land surface temperature (LST), Maximum Entropy algorithm used to determine the health, distribution, and richness of forest ecosystems; to understand characterising ecosystem functions (Batisani and Yarnal 2009; Avtar et al. 2020) This is an indicator of vitality. Differential and Persistent Scatterer SAR Interferometry (DInSAR and PSI) and Object Based Image Analysis (OBIA) for Earthquake and landslides causality assessment (Singhroy et al. 2002) as an indicator for measuring vulnerability. Single and two ellipse methods; CORINAIR methodology; Doppler centroid values; high radar cross-section (RCS); signal-to-clutter ratio (SCR) for measuring traffic flow pattern and management, travel time estimation (Avtar et al. 2020)as an indicator for measuring versatility. Estimating consumption expenditure and asset wealth from high resolution satellite imagery as a proxy for predicting poverty (Jean et al. 2016). The methodology adopted is transfer learning using CNN and night time imagery for detection of human activity as a measure for assessing vitality.

Figure 1 depicts schematically how the remote sensing data could relate to the socio-economic data.

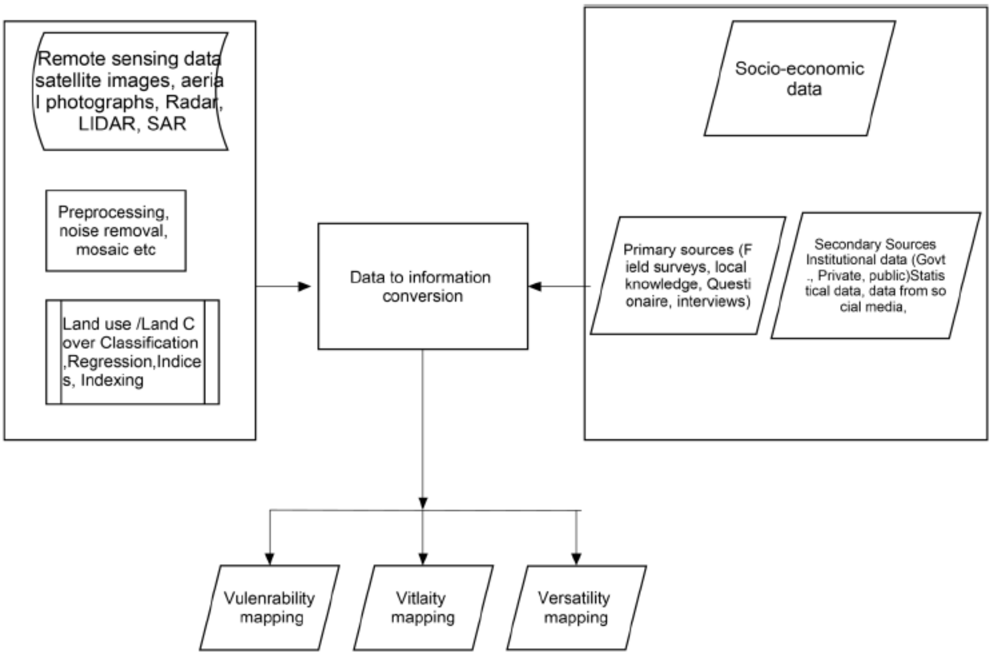

Figure 1. Linking remote sensing data to socio-economic data

3. BAVARIAN CASE STUDIES AND FIELD VISITS

As a first start to evaluate the 3VRUT indicators in Bavaria both the data collected and presented by the Land Atlas (https://www.landatlas.de/), the Bayern Atlas (https://geoportal.bayern.de/bayernatlas/) and the data underlying the most Bavarian territorial development plan[1] are useful. From these combined data we choose two cases studies which were expected to show significant variations and differences in the 3VRUT indicators based on their development assessments. The two chosen cases of villages were Bayerisch Eisenstein and Obermichelbach-Tuchenbach. Bayerisch Eisenstein is a small village at the border with the Czech Republic and relatively far away from a major city. It has a relatively small population which is also declining gradually. Its location close to mountainous and forest areas makes it suitable for various kinds of tourism, yet partly due to the recent pandemic this has sharply declined. There is a regional train connection. Obermichelbach-Tuchenbach is also a small village, which is however comparatively closer to a larger city. It has close spatial connections to major economic industries, such as the Adidas factory.

In preparation for a more detailed data collection exercise and in support of the 3VRUT indicator development we carried out two first field visits, to obtain a first impression of the villages. The visits were prepared by assembling detailed geospatial data from the villages available via the public platforms and by indicating a number of points and areas in each of

[1] https://www.landesentwicklung-bayern.de/fileadmin/user_upload/landesentwicklung/Dokumente/Instrumente/Landesentwicklungsprogramm/Landesentwicklungsprogramm_Bayern_-_Nichtamtliche_Lesefassung_-_Stand_2020/LEP_Stand_2018_Anhang_2_-_Strukturkarte.pdf

the villages which were of specific interest from a vitality, vulnerability, versatility and vulnerability point of view. During the field visits we aimed to discuss remarkable visible features which would be of interest to these indicators. Tables 1 and 2 present some basic geospatial statistics of each of the villages.

class	Pixel sum	%	Area (m^2)	Pixel sum	%	Area (m^2)	Change %
Built-up	46120	7.44	1037700	29590	4.7	6657750	-36
Water	0	0	0	3760	0.6	846000	0
Agriculture	52900	8.53	11902500	14530	2.3	3269250	-73
Commercial	0	0.00	0	6060	0.9	1363500	0
Forest	35080	56.59	78930000	34940	56.3	78615000	0
Grass	12227	19.72	27510750	19817	31.9	44588250	62
Bare	47830	7.72	10761750	18410	2.9	4142250	-62

Table 1. Basic spatial land use features in Bayerisch Eisenstein

Class	Pixel sum	%	Area (m^2)	Pixel sum	%age	Area (m^2)	Change %
Built-up	34600	5.12	7785000	39450	5.84	8876250	14
Water	2850	0.42	641250	3580	0.53	80550	26
Agriculture	53110	7.87	11949750	90670	13.43	20400750	71
Commercial	1190	0.18	267750	6040	0.89	1359000	408
Forest	220010	32.59	49502250	238630	35.34	53691750	8
Grass	89580	13.27	20155500	109720	16.25	24687000	22
Bare	273840	40.56	61614000	187090	27.71	42095250	-32

Table 2. Basic spatial land use features in Obermichelbach-Tuchenbach

When starting the exploration of available satellite images for the selected rural towns of Bayerisch Eisenstein and Obermichellbach - Tuchenbach we faced several challenges of finding and connecting data which would indicate one or more aspects of the 3VRUT directly. One of such challenges included connecting the data to identify the spatio-temporal features with respect to their spectral, spatial, radiometric and temporal resolutions. Although Earth observation data is increasingly available at different scales and contains a wealth of information about landscape features which can be indirectly correlated with socio-economic activity, there are no standard methods to derive such features.

From the visual inspections we assembled various types of features which we considered relevant for the further development of the 3VRUT indicators. These included the following:

In Bayerisch Eisenstein:

- It became directly visible from the number of hotels, pensions and bed & breakfast features that the village very dependent on tourism. Given that the visit took place during strict corona restriction there were obviously a very limited number of tourists visible in the streets and makes the village limited in vitality. One can furthermore immediately understand that the resulting limited income will have serious consequence for the vulnerability and resilience of the village.
- There were several signs visible in the village of locally organised events in village centre, such as music events and season specific festivities. Such signs are obviously not necessarily visible via spatial features unless the spatial images are taken at the time of the event itself.
- During our first visit it was noticeable that there were relatively many empty and vacant houses, offices. The owners had left due to retirement and lack of any succession. Whilst this is a common problem in relation to versatility and resilience, this issue may be difficult to measure through remote sensing. Empty buildings may be detectable, but the social fact of retirement and/or lack of follow up requires additional context.
- The local school seemed closed, and after further enquiry it turned out to have closed due to too few school children. As a consequence, currently school children are picked up by school bus. Again, this vitality aspect is known in socio-development literature, but the social trend, which may be very gradual, may not be in sync with the discrete nature of remote sensing images. The physical artefact which may be visible and detectable are school bus stops and the active use of bus infrastructure. The socio-demographic changes need then to be aligned with such artefacts.
- The decline of economic activities has resulted in the fact that many people work elsewhere. Hence, the village has become a forensic village. This fact may be visible by more frequent road use, resulting in faster decay of roads comparatively. One would need some sort of geospatial comparison to detect this.
- The local restaurant seemed a social meeting point of the village. This is in itself not uncommon, and can be assumed once the building is detected. How, how frequent and when social activities take place is however a key component of vitality. This frequency may not be in sync with the trends analysis of remote sensing images. -
- There was no apparent presence of renewable energies. This may seem an indicator of vitality.
- Being at the Czech border the socio-economic link with the neighbouring town on the other side may be visible with physical artefacts. A clear artefact is the presence of the joint station through which there is a territorial border.

- Being close to a national park, one may assume a number of spatial restrictions, related to environmental protection. .

In Obermichellbach – Tuchenbach:

- One of the first visible impressions included the presence of an older centre and several rings of new construction developments. This gradual spatial development of the villages suggests a relatively stable socio-economic development. This spatial connection - having regular circular expansions may be an indicator for resilient village development.
- Certain parts village of the village were occupied by relatively large houses and plots of land. Such plots are clearly an indication of relatively above average income levels, suggesting possible economic vitality. Calculating an median plot size from remote sensing may thus be a relative indicator of vitality
- There were certain unused plots of land within the village. This would at first sight suggest absentee ownership or delays in land use plans. Such artefacts may be an indicator problems with vitality.
- By visual inspection of the area we discovered a clear presence of renewable energy initiatives, such as many solar panels and biogas facilities. These artefacts, which are also detectable by high resolution images are an indication of vitality.
- A feature which was noticeable was the presence of several new or well-maintained local play gardens for children. This suggests the presence of children and thus vitality in the village.

4. DISCUSSION

A number of socio-spatial features are not clearly visible in the landscape but are clearly visible through direct inspection. In these cases one requires indirect proxies to detect there features. Indirect proxies are for example necessary for understanding the frequency and significance of social meeting points. Although the buildings or locations are visible the rate and relevance of these locations require detecting additional features in the vicinity of these artefacts, such as use of parking places, changes in land cover and green features. Certain features, such as the occurrence or frequency of events and activities (relevant for vitality for example), may not be directly visible via remote sensing, as they may occur at different times than the image capture.

One of the features which may need closer attention in the development of a 3VRUT methodology is the presence of renewable energies. This feature is relatively good visible via images and may also serve as an indirect proxy of a certain degree of development. Investments in these facilities may relate to resilience and versatility. Hence, finding gradual trends of such artefacts is likely to coincide with multiple ecological and economic advantages detectable in spatial planning statistics.

Associated with this national parks or visible green features are usually certain spatial access and use obligations and restrictions. These are obviously not directly visible or detectable, but need to be inferred from other observations. Similarly, the presence of gardens around residential houses suggest a certain level of income, hence a certain degree of wealth or difference between social classes. In this case on has to detect and calculate composite spatial variables, such as average garden size per house(hold), or number of gardens as compared to number of buildings.

Certain features such as schools, restaurants, small and medium enterprises, are crucial for identifying or inferring the respective economic 3VRUT indicators. Knowing how and when these buildings are occupied is however crucial to derive relevant socio-economic insights. An additional issue is the question which number of people these locations serve and whether these numbers are sufficient. Such aspects need to be derived from the use of other features, such as roads.

5. CONCLUSION

Remote sensing can indeed analyse changes in spatial artefacts visible through changes in land use, land cover, and land densities. These can indirectly reveal certain elements of land ownership, land use rights, infrastructure and environmental development, which are each relevant to measure each of the 3VRUT factors. Additionally, there are a number of socio-economic data which can reveal changes in social spaces and social relations. Yet the rate and type of observed changes by either approach are not in sync, suggesting that there are hidden patterns which cannot be observed by single methods. Integrating the 3V indicators with different types of data acquisition methodologies faces both epistemological and socio-institutional hurdles. Additionally, there are problems of spatial scale, privacy, adaptability of collection methods and sustainability and usability of the collection tool itself. There are several findings which can contribute to developing the geospatial part of the 3VRUT framework further. First of all, it is likely that geospatial data will become more abundant than ever before via user-friendly open portals and web applications. We have learned by experience that for the Bavarian case specifically there are both the possibilities of so-called Geoportal Bayern and the Bayern-Atlas where data can be directly put to use. Many of these data can serve as a direct source to contribute to the assessment of the major aspects of 3VRUT, even though they do not directly lead to 3VRUT assessments. Additionally, open platforms such as google’s earth engine help to make some of the calculations and develop some of the required algorithms which may be put to use via machine learning. Finally, the developments of digital twins may help to generate some basic models of spatial features, both in urban and in rural regions. However, most of the data and platforms are still too much focused on bio-physical assessments, especially when it comes to the crucial aspects of the 3VRUT. There is therefore still a need to develop further proxies and combined constructs which are better capable of assessing the specific 3VRUT aspects and indicators through the use of remote sensing.

Secondly, there can be a debate as to whether such data and indicators should be collected by public or open platforms or by systematic voluntary contributions. The dilemma in this case is the capacities which may exist at local rural levels to actively contribute to the data collection in case the automatic derivation via remote sensing is insufficient.

To develop the geospatial detection of 3VRUT indicators further, the next steps will focus on testing the data collection process and the alignment of socio-economic data with the geospatial data in the specific villages and case areas further. The data collection should reveal which data can actually present a sufficient and relevant image of the changes and the trends in each of the villages. Additionally, it will be necessary to test and validate how remote sensing can directly and indirectly contribute to detect such changes automatically. The starting point is therefore not the remote sensing images and automation of detecting itself, but the relevancy and significance of single and composite indicators which provide meaning to the 3VRUT. Furthermore it is important to deduct which changes in the 3VRUT aspects are idiosyncratic and which ones are systematic or universal.

Recommendations for further research include comparing the German case study research with the Japanese, Polish and Spanish results. Such a comparison should reveal on the one hand the influence of contextual, landscape and institutional factors play a role in the respective 3VRUT aspects and on the other there are spatial, temporal and/or systematic patterns. Finally, the relation between indicators and spatial policy preparation and implementation needs to be investigated.

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BIOGRAPHICAL NOTES

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