Network landscape representation: ecosystem services context

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Abstract. Mostly ecosystem problems concern contradictions between extensive land use and cover in the context of sustainable agricultural landscape. Environment governance along with land use planning and development requires thorough consideration of capacities and flows of ecosystem services and concomitant goods as well. Pertinent assessment is usually performed through mapping techniques. However, experts emphasized the need to find and apply novel means of presenting the structure and dynamics of service-providing entities. This paper introduces a brief characterization of landscape of the Oka district (Republic of Buryatia, Russia) in novel network scope with aim to provide further possible tradeoff between traditional land use and ecosystem sustainability.

1. Introduction

Ecology remains in the center of modern societies in diverse aspects for decades. Thus, the Human Sustainable Development Index (HSDI) was proposed in 2009 as a way to ennoble the United Nations’ Human Development Index (HDI) by joining carbon emissions per capita as an environmental metric [1].

Also researchers and practitioners consider environment services (ES) as a capital which societies should reinvest to if support its sustainability [2]. Some authors demarcate ecosystems’ capacity to provide and services and an actual utilization of these services (so-called flows) while assessing to understand how sustainable the utilization is [3].

Environment governance along with land use planning and development requires thorough consideration of capacities and flows of ecosystem services and concomitant goods as well. Pertinent assessment is usually performed through mapping techniques. Mapping of ES is valued as reliable way to clarify the benefit of interacted ecosystems and their components they deliver to human societies for
reasonable planning and decision-making. However, experts emphasized the need to find and apply novel means of presenting structure and dynamics of service providing entities [2].

Many real-world geo-spatial systems can be represented as networks so it seems attractive to involve discrete underlying spaces (e.g. lattices or networks) into consideration of problems on ecosystem services and their vulnerabilities.

Such interesting geographical zone as rural Oka district, Buryatia, RF might be of special pattern to test new effective ways for ES analysis and pertinent diverse socioeconomic assessments and comparisons.

2. Related work

Many scholars showed that a number of factors connected to exploitation of natural resources make ecosystem services crucially vulnerable to the impact [4].

Traditionally Siberian rural ecosystem services are represented by farming, timber harvesting and some other activities.

Through over the world intensive farming has promoted debates on environmental impacts and food safety long ago. In this regard, diverse sustainability indicators and techniques have been developed to avoid subjective opinions and decisions [5].

For example, Amazon Data manifested the influence of livestock on cover such as deforestation is of lesser significance than that of fires [6]. The paper [7] clarified to what extent government subsidies affect farming intensities and owners’ income.

To move forward in ecosystems services issues the work [8] recently elaborated a generic scope including germane metrics for environmental impacts of farming and applied those on some examples within Ireland.

Thus, reliable and accessible information on landscape and land use is needed for many reasons [9]. These concern oversight on social and economic aspects of the territory and large-scale public health in whole and epidemiological situation particularly.

Network science as a compelling research paradigm that can intuitively portray complex systems, has been utilized in geographic information science for reviews, assessments, and projections for the last two decades, mostly for network-like geographical entities [10].

Nevertheless, several geo-spatial studies involve productive techniques of complex networks, for example, in precipitation research considering corresponding maps as network-unlike entities. Thus the complex network science was used to scrutinize spatial dynamics of annual precipitation (as network-unlike entity) so that a germane network was erected by associating a node to a geographical zone, characterized by temporal precipitation distribution, and defining pertinent links among nodes [11]. The inferred network demonstrated essential spatial variability with weakly connected zones and highly connected ones both.

3. Data and Methods

In network conceptualization we apply in the current work, network elements – nodes and links – are associated with ecosystem components and their interdependencies, respectively.

It should be noted that regular network analysis usually considers network-like objects and processes in format of static datasets and apply effective graph metrics to those. However, recent studies put in focus representation and examination of dynamic network structures embedded in geographic space and aggregating timely and relevant geospatial data [12].

The study zone (Oka district, Republic of Buryatia, Russia) is located close to the interstate Russian-Mongolian border in the watershed area of the Lake Baikal and represented by two contraposed natural geographic macrosystems - the North Asian barren-taiga and Central Asian desert-steppe. Specific interaction processes between those of endogenous and exogenous character formed the landscape features, i.e. relict landscapes.

The ecosystem services that are traditional to this zone include dry-stock farming, timber harvesting, and prospective collection of non-wood forest products as wild berries, plants, and nuts. These activities
affect the ecosystem and require to seek for a balance between its conservation and production of goods and services to provide sustainable development of the district. One of the approaches to achieve this goal might be quantitative analysis of the landscape on network platform.

In line with our principle concept of networkalization of network-unlike entities [13] the technique was utilized to convert several landscape maps of some regions and districts into networks. Not only patterns of the Oka district in two different scales (1:100 000) [14] (figure 1) and (1:25 000) [15] (figure 2) were taken into consideration. But also those presented by maps of Popielow district, Poland (1:10 000) [16], Georgia (1:1500 000) [17], and Olkhon district, Irkutsk region, Russia (1:200 000) [18] were processed and compared.

![Figure 1. Oka District landscape (Scale 1:100 000).](image1)

![Figure 2. Oka District landscape (Scale 1:25 000).](image2)
4. Findings
As mentioned above, the landscape maps (of diverse scales) were networkized (converted into networks) to compare and analyze their graph metrics. Such an effective instrument as Gephi software [19] was used to calculate the metrics and visualize the networks.

Topologies of the relative networks are portrayed on figure 3.

![Networks](image.jpg)

**Figure 3.** Network fingerprints of the landscape maps - a, b - Oka district, Republic of Buryatia, RF (1:25 000) and (1:100 000) respectively, c - Olkhon district, Irkutsk region, RF (1:200 000), d - Georgia (1:1500 000), and e - Popielow district, Poland (1:10 000).

The table displays network metrics that characterize the studied landscapes.

**Table 1.** Network metrics of the landscape patterns.

| Metric, $G_{ls}$ | Georgia, 1:1500 000 | Olkhon, 1:100 000 | Oka, 1:100 000 | Oka, 1:25 000 | Municipality of Popielów, Poland, 1:10 000 |
|------------------|---------------------|------------------|----------------|--------------|-------------------------------------------|
| $N$              | 23                  | 55               | 24             | 52           | 19                                        |
| $L$              | 32                  | 100              | 36             | 86           | 33                                        |
| $D$ diameter     | 6                   | 10               | 6              | 11           | 5                                         |
| $<\lambda>$      | 2.9                 | 4.04             | 2.73           | 4.44         | 2.54                                      |
| $<k>$ average    | 2.8                 | 3.6              | 3.0            | 3.3          | 3.8                                       |
| $S$ density      | 0.126               | 0.067            | 0.13           | 0.065        | 0.193                                     |
| $<C>$ clusterization coefficient | 0.52 | 0.543            | 0.58           | 0.482        | 0.54                                      |
| $M$ modularity   | 0.46                | 0.66             | 0.42           | 0.64         | 0.41                                      |
| $k_{max}$        | 9                   | 10               | 11             | 9            | 7                                         |
5. Discussions
Instead of presenting a brief characterization of landscape traditionally, we suggested a network description of the territory that might be useful for further best and optimal tradeoff between landcover and land use. It can be seen that the network metrics demonstrate a wide spectrum of values that all depend on a district a scale as well. It is clear that some more efforts should be attempted to understand interconnection between the metrics in network space and observable macroscopic ecosystem phenomena. Nevertheless this step to introduce such a comparable network analysis in the domain is done. Context specific metrics (CSM) based on Agri-environmental Footprint Index (AFI) similar to those elaborated by [8] seems of value to assess environmental impacts of agriculture activities. Within this context the researchers underlined a significance of expert and stakeholder’ input in developing meaningful CSM. It is essential that such multi-metric scope combine several relevant indicators to target on more complex environmental units.

Also it is of value to put attention to perspective CA-Markov model [20] which gives a foundation to predict spatial patterns of land use in future by taking into consideration dynamic changes in land use patterns utilizing remote sensing and GIS.

6. Conclusions
On the whole obtained results show that the combination of techniques and data from geographic information field and concomitant domains deployed on network platform develops additional means to describe and analyze complex spatial socio-economic and environment systems. The suggested modelling platform is both general, flexible enough, and applicable for modelling a variety of real ecosystems with simple metrics to characterize, explore and compare network nature of diverse real spatial patterns. The proposed platform fits within larger ranges of sustainability problems, e.g. for land use systems and pertinent complex network modelling.

Acknowledgements
The study was funded by RFBR and MECS, project number 20-57-44002 “Interdisciplinary network platform for modeling socio-economic and environmental processes in the cross-border territories of the Russian Federation and Mongolia with limited transport accessibility”.

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