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Climate change effects and their interactions: An analysis aiming at policy implications

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ABSTRACT

In this study we provide a computerized graph structure for synthesizing and displaying the data on a region's ecosystem-economic system. By applying Mathematica-based graph modeling we create a causal network of the synergistic impact mechanism among certain climate related factors. Our computational approach identifies a climate factor that affects most immediately or most strongly the others. Important factors are indicated through the use of graph theoretical tools. Our graph-based approach and its computational aspects allow for factor ranking(s) according to their importance to the network both numerically and visually, for certain settlement types. Our contribution provides quantitative estimates of impacts and adaptation potentials of five potential effects of climate change (migration, flooding-landslides-fire, air and water pollution, human health and energy-water-other resources) which play a substantial role at the synergistic impact mechanism. By using graph visualization techniques, the structure of the synergistic impact mechanism is self-evident. Specifically, graph layouts are created to detect i) the causal relationships of the synergistic mechanism under study ii) the most influential factor(s) in the synergistic mechanism and iii) classify the factor's roles (based on the degree of their impact) within the coping mechanism. Highlighting graph elements let information for policy implications stand out.

1. Introduction

We conduct an analysis of environmental impacts referring to certain categories of settlements. We consider settlements as ecosystems vulnerable to climate-change related factors. One factor could have an environmental impact on many more. Within the framework of the synergistic mechanism of environmental effects, we find that network-based measures may provide important insights into recognizing the key factors in a given ecosystem. Understanding the influence of climate change on human settlements and the associated socio-economic effects is a major challenge (Halkos, 2013; Halkos and Matsiori, 2012).

In a previous computational approach of the same issue (Halkos and Tsilika, 2014), infinite matrix representations of influence patterns per settlement type were constructed. In the present approach, the synergistic impact mechanism is captured in one graph-theoretic formulation. Similar graph structures for economic models have been computed in Cerina et al. (2015) and Halkos and Tsilika (2016).

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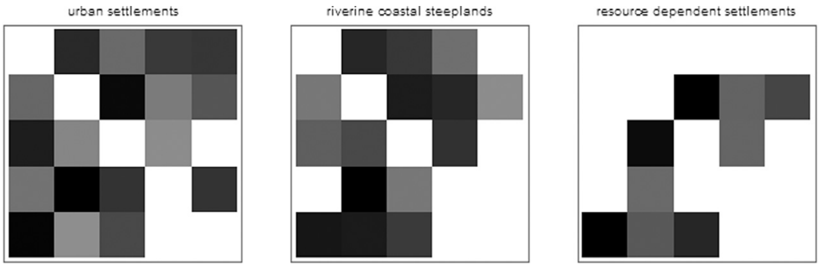

Fig. 1. Matrix of synergistic effects for urban settlements, riverine coastal steeplands and resource dependent settlements.

In the proposed graph structure each environmental factor corresponds to a node and the synergy from one factor to another constitutes a (possibly weighted) directed edge. This way, we create a causal network of the synergistic impact mechanism among certain climate related factors.

The issue of finding the "important" nodes in the causal network of synergistic effects is first confronted. Important nodes are indicated through the use of graph theoretical tools. Nodes (factors) with a key role in the causal network of the synergistic impact mechanism have high centrality indicators. Usually indicators of centrality reveal the ideal route from a source to a target in order to find a shortest path or to maximize flow (Blöchl et al., 2011). Here, indicators of centrality identify the most important nodes within a graph. The question of which nodes are the most central has multiple answers. Definition of "central" varies by context or purpose (Freeman, 1979; Aroche-Reyes, 1996; Friedkin, 1991; Everett and Borgatti, 2005; Borgatti, 2005; Borgatti and Everett, 2006). In some cases the number of connections is the best centrality measure, in other cases "central" is relative to rest of network. In our analysis, we evaluate each indicator of centrality as an influence metric and give its interpretation in the environmental context we set. Extending and exploiting this information, we proceed in identifying "key" factors and rank the factors' roles in a given synergistic impact mechanism. A certain algorithm for node coloring is employed for visual testing of linkage criteria.

The ultimate result of this study is the visual output, since we succeed to evaluate the synergetic interactions through a pseudo-geometric visualization, in a self-explanatory approach, free of any mathematical formulations, arguments and/or any other justification.

2. Visualizing interactions among climate related factors for three settlement types

In this section, we justify our assumptions for three types of settlements (i.e. urban settlements, riverine coastal steeplands and resource dependent settlements) on the findings of IPCC (McCarthy et al., 2001), par. 7.6.2. Specifically, we take the interactions between migration, phenomena of flooding-landslides-fire, air and water pollution, human health and energy-water-other resources as featured in a tabular format in the IPCC report (McCarthy et al., 2001) chapter 7.

Our previous visual approach (Halkos and Tsilika, 2014) is summarized in Fig. 1. In visual outputs of Mathematica's environment, matrix cells with different shades of gray show the degree of influence of the synergistic effect. Our color rule says that a white cell states no interaction; grey-shaded cells signify interactions of variant influences. A dark shade is related to an intense impact.

In the pattern constructs below, while white cells are steadily white, all other cells fluctuate their shades regionally, depending on the geographic, seasonal and/or sectoral level. The derived matrix patterns are representative of every type of settlement. Rows and columns of matrices in Fig. 1 feature five environmental factors with a serial number from 1 to 5. Serial numbers 1–5 represent Migration (1), Flooding-Landslides-Fire (2), Air and Water Pollution (3), Human Health (4) and Energy-Water-other Resources (demand) (5).

Relevant concepts and notions are agriculture, forestry, transportation, infrastructure, extinction of species and loss of ecosystems, heat waves etc. The IPCC report 2001 states that "in the 20th century, global temperatures increased in the range of $0,6 \pm 0,2$ °C and provide a number of possible effects of global warming on climate like extreme weather events (with very possible summer droughts in continental areas, higher heat waves, etc.), tropical storm intensity (hurricanes, etc.), decomposition of methane hydrates, etc".

The visual approach presented in this paper, employs graphs with nodes the climate-related factors and edges their in-between interactions. Fig. 2(a), (b), (c) provide a topological view of the matrix patterns of Fig. 1. In all figures, we consider synergy effects that occur with equal probability in any climate related factor and consequently, we construct unweighted graphs. We assume a flow process in which no link is repeated (i.e. only the immediate synergistic effects are considered) and, synergy flows by parallel duplication (Borgatti, 2005). We do not approach the system with a dynamic model-based view; the dynamic flow context is out of the scopes of the present study since (i) a secondary (undefined) synergistic mechanism takes place after the first activation of the synergistic mechanism and (ii) priority has been given to prevention measures and policy interventions based out mostly on the primary synergistic mechanism. Following Borgatti's (2005) categorization, we study the case of "diffusion by replication". We consider shortest paths (i.e., the geodesic distances) in the sense of direct/immediate impacts.