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A Taxonomic Analysis of Perspectives in Generating Space-Time Research Questions in Environmental Sciences

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ABSTRACT

Research questions in environment science can be decomposed into three basic dimensions: space, time and statistics. The combinations of these three dimensions reflect the diverse perspectives of observations across multiple scales. One can classify these scales into four types: individual, local, meso, and global. Following this multi-dimensional and multi-scale framework, this paper conducts a taxonomic analysis that systematically classifies research questions in environmental science. This taxonomic analysis includes papers from a leading environmental science journal. The results show that the majority of research questions are directed at local and global scale analyses. Studies that incorporate many scales of analysis are not necessarily more sophisticated than studies that investigate a single scale. Nonetheless, it's beneficial to explore more possibilities by investigating data at different perspectives. This taxonomy could help generating research questions and providing guidance for building analytic workflow systems to fill the gaps in future scientific endeavors.

KEYWORDS

Environmental Science, Research Questions, Scale, Space-Time, Taxonomic Analysis

INTRODUCTION

The frontiers of environmental science studies have been driven by hypotheses which are posed by researchers observing the living things and their surrounding settings (Botkin & Keller, 2010). These hypotheses are then formalized into research questions and tested through rigorous scientific investigations. Since environmental problems are related to real-world issues, research questions in environment science can all be decomposed into three basic dimensions: space, time and statistics.

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The spatial dimension defines the geographical objects and range of the study, such as gauging stations along rivers and the drifting objects in the ocean. The temporal dimension represents the span of the study, and the intervals of observations collected range from seconds to years. The statistical dimension exhibits the arrangement of attributes in the statistical space. These three dimensions are actively intertwined with each other and are inseparable in the analytic process (Ye & Rey, 2013). Over the last few decades, an increasing abundance of available space-time data in various domains is seen (Batty, 2005; Mennis & Guo, 2009; Ye & Shi, 2012). These big data are efficiently collected thanks to the growing capacity and ubiquity of information and communication technologies (Wang, Wilkins-Diehr, & Nyerges, 2012; Yang, Raskin, Goodchild, & Gahegan, 2010). In the meantime, numerous mathematical and statistical models have emerged with the technological and methodological advances. These models are dispatched through both commercial and open-source software packages, which greatly lowered the barriers for sophisticated and large-scale scientific computation (Anselin, 2012; Bivand, 2011; Rey & Anselin, 2010; Steiniger & Hunter, 2013). Benefiting from these advancements, researchers are able to look at data from multiple dimensions, new research questions can be identified this way.

Environmental investigation involves the descriptions and predictions of complex and high dimensional processes (Cressie & Holan, 2011). The diversity of perspectives is essentially the combinations of spatial, temporal, and statistical dimensions of different observations at different scales. Researchers of environmental science deal with heterogeneous data collected from numerous sources, thus it's critical to be aware of difference of the raw data (unit of observation) and the data of interest (unit of analysis) (Ye & Rey, 2013). While the unit of observation is defined by the data collection process, the process itself is not always determined by researchers. The unit of analysis, on the other hand, is related to how the data are analyzed, interpreted, and framed by the research question. This conceptual difference indicates that the unit of analysis is represented by multiple underlying units of observations through processes such as aggregation, partition, or sophisticated statistical methods. Different types of unit of analysis thus lead to different perspectives of looking at the same data. This diversity of perspectives essentially reflect the scales of the analysis in the three basic dimensions.

The notion of scale in spatiotemporal analysis is often considered as the level of detail of a geographical data set, related to how data should be represented, operated and analyzed (Andrienko et al., 2010; De Smith, Goodchild, & Longley, 2007; O'Sullivan & Unwin, 2003). This quantitative notion of scale focuses on the resolution and extent of the spatiotemporal data (Goodchild, 2011), and has been studied extensively in related disciplines of environmental science such as ecology, geomorphology, and hydrology (Inkpen, 2011; Simon, 1992; Warke & McKinley, 2011; Yan, Wang, & Chen, 2011). The qualitative notion of scale (Ye & Rey, 2013), on the other hand, represents how data are analyzed in a comparative context, signified by different types of unit of analysis being applied. Based on its relationship to the unit of observations, Ye and Rey (2013) classified the scale of the unit of analysis into four types: individual, local, meso, and global. This view is beneficial since in any of these three dimensions, dependence is the rule rather than exception (Rey & Ye, 2010). The unit of analysis at the individual scale represents a geographical location, a temporal label, or a statistical measure. At the local scale, the unit of analysis explores a group of units formed by the focal observation and its neighboring observations in one of the three dimensions. A meso-scale analysis studies a group of entities that shares similar feature(s) in spatial, temporal or statistical distributions, which differs from the local scale analysis where one unit is picked as the focal observation. Therefore, the meso-scale analysis usually has a larger subset of the unit of analysis than the local-scale analysis does. Finally, the analysis at the global scale examines the distributions of all the spatial locations, times, or attributes. This domain-neutral view of scale allows us to systematically classify different

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