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Surrogate indicators for assessing community resilience

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Abstract

The importance of community resilience to natural disasters is being increasingly recognised. This paper presents an approach for the development of surrogate indicators for comprehensive assessment of community resilience, which is crucial in the context of predicted increase in natural disasters resulting from extreme weather events due to climate change. The use of surrogate indicators is advocated because a comprehensive assessment of community resilience across various thematic areas and associated key areas requires the measurement of a large number of resilience indicators which is not always feasible due to time and resource constraints, To overcome this, researchers tend to use secondary data sources, which are easily available but not always reliable. This highlights the need for surrogate indicators that are easy to measure from reliable primary data sources and are adequate to capture the resilience of a community.

Firstly, the paper discusses the two approaches for defining and conceptualising community resilience and the need to account for the complex interrelationships between thematic areas, key areas and resilience indicators and their implications for research. Secondly, a comprehensive framework for the assessment of community resilience is proposed and the difficulties associated with the measurement of overall resilience of the community are discussed. Thirdly, the paper explains a two-step approach to develop surrogate indicators highlighting the necessity and challenges associated with it. Finally, the proposed approach is elaborated with a simple example for better understanding.

Keywords: Resilience indicators, adaptive capacity, disaster, composite indicator, resilience framework

1. Introduction

A predicted major effect of climate change is the increased frequency and intensity of extreme climate events which can result in an increase in large-scale natural disasters (Jentsch et al. 2007). Therefore, there is an urgent need to build stronger communities with a greater degree of resilience to natural disasters. From past disaster experience, it is evident that some communities recover at a relatively rapid rate, whereas certain other communities take years to recover. For example, some people affected by the Indian Ocean Tsunami in 2004 are still living in temporary settlements in Sri Lanka after almost a decade (Mulligan & Nadarajah 2010). Consequently, it is necessary to investigate and compare the resilience characteristics of different communities to identify qualities or attributes that facilitate or inhibit post-disaster recovery. This knowledge is essential to develop policies and programs for the enhancement of the resilience of a community.

In this context, it is important to develop reliable and consistent methodology to assess the resilience of a community. Several studies have focused on developing a framework for assessing the resilience of the community to disasters (Ford & Smit 2004; Chang 2010). However, these studies have tended to differ through their emphasis, scope and definition of what constitutes community resilience and how community resilience can be most effectively and accurately assessed. These limitations are attributed to the common approach of viewing community resilience through a mono-disciplinary lens. Therefore, it is necessary to develop an integrated conceptual framework that takes into account the complex interplay of ecological, economic, infrastructural, institutional and social attributes associated with community resilience. The framework can be operationalized using a range of resilience indicators to suit the nature of a disaster and the specific characteristics of a study region.

The accuracy of the framework in capturing the community resilience to disasters depends on the comprehensiveness of the resilience indicators chosen for investigation. Comprehensiveness requires the measurement of a large and diverse range of resilience indicators and in-depth assessment of their relevance and importance within a given context and may change depending on the nature and extent of the disaster. This is because community resilience is multifaceted and needs to consider the attributes related to ecological, economic, infrastructural, institutional and social dimensions that make up a community (Bruneau et al. 2003). However, collecting reliable and accurate information on a large number of indicators may not be feasible in terms of resources and time requirements. Thus, a practical approach is to identify a suite of surrogate indicators that can facilitate the prediction of the majority of indicators based on a relatively small number of indicators. Such approaches have been successfully employed in other research domains. For example, Miguntanna et al. (2010) developed easily measureable surrogate indicators to predict water quality parameters that are relatively tedious to measure.

The objective of this paper is to explore the fundamental concepts related to surrogate indicators and the challenges in their usage in community resilience investigations. Firstly, the paper introduces the concept of community resilience followed by a framework for assessing community resilience. Then, the necessity and challenges related to the development of surrogate indicators are discussed.

2. Community Resilience – Definition

Community resilience is defined in research literature depending on the context of the problem that has been investigated and on the expertise of the investigator. As such, the definition of community resilience varies considerably preventing a uniform conceptualisation of community resilience (Kahan et al. 2009). A primary difference in the approaches to defining and conceptualising community resilience is that some view resilience as a reactive outcome, while others consider it as a proactive process.

Horne and Orr (1998) defined resilience as “a fundamental quality of individuals, groups and organisations, and systems as a whole to respond productively to significant change that disrupts the expected pattern of events without engaging in an extended period of regressive behaviour”. This definition identifies resilience as an outcome or reactive response. In contrast, UNISDR (2005) defines community resilience as “the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure, which is determined by the degree to which the social system is capable of organising itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures”. This definition portrays community resilience as a proactive process that will lead to a desirable outcome when a disaster occurs.

Manyena (2006) discussed in detail the consequences of these two approaches in conceptualising community resilience. When community resilience is considered as an outcome, emphasis is placed on achieving the set outcome by using the available resources without considering the demands of the community during the disaster. In particular, this approach generally disregards the role of the community in disaster recovery planning, leading to undesired outcomes. On the other hand, human and community involvement are recognised and encouraged in the proactive process approach as a crucial characteristic of a resilient community. Adaptation to future challenges based on past experience is also seen as another characteristic of a resilient community since adaptation can enhance the resilience of the community by mitigating future disaster risks identified from past disaster experience.

For this reason, the proactive approach to community resilience has enjoyed wider coverage in literature because it can potentially empower and build stronger communities (Simane et al. 2012; Keys et al. 2013). However, it requires a comprehensive evaluation of the resilience of the community based on either past disaster experience or a hypothetical disaster situation. Consequently, it is important to develop a robust and comprehensive framework for the assessment of community resilience. Such a framework should be holistic by considering various dimensions of community resilience and it should also be able to be adapted across different disaster types, disaster scale and local characteristics. For this reason, the definition of community resilience as adopted in this research refers to “a set of capacities that can be fostered through interventions and policies, which in turn help build and enhance a community’s ability to respond and recover from disaster” (Cutter et al. 2010).

3. Framework for assessing community resilience

The framework proposed in this paper consists of thematic areas, and its sub categories of key areas and resilience indicators as shown in *Figure 1*. Community resilience is a complex concept involving various dimensions that make up a community. In broad terms, there is a general consensus in the literature that community resilience consists of five main areas (Bruneau et al. 2003), which are referred in the proposed framework as thematic areas. They are ecological, economic, infrastructural, institutional and social resilience. Hence, the overall community resilience can be considered as the function of these five thematic areas:

Community resilience = *f* (ecological, economic, infrastructural, institutional and social resilience)

The second layer of the framework is the key areas, which are derived by further partitioning each thematic area in order to comprehensively capture the characteristics of each thematic area for community resilience assessment. *Figure 1* presents an example of key areas which need to be determined by a multi-disciplinary panel of experts by considering factors such as local risks, vulnerabilities and the scale of the anticipated disaster. Additionally, the importance of each key area can also vary depending on these factors. Hence, an appropriate priority or weighting system has to be decided by considering their relative importance. Finally, the primary indicators that can encapsulate each key area need to be determined with the consensus of the expert panel before data collection. These indicators are again highly subjective and can vary considerably depending on the context of the disaster and its associated attributes (*Figure 1)*. Detailed explanations of *Figure 1* are provided in a separate paper currently under development by the authors.

In order to capture the overall resilience of the community, past studies have generally focused on developing a composite indicator, as a linear combination of individual indicators with weightings as coefficients, i.e. ax+by+cz, where x, y and z are indicators and a, b and c are weightings (Cutter et al. 2010). The weightings are generally assigned using one of three methods: (1) expert opinion on the relative importance of the indicators, which are based on the theoretical understanding of the relationship between indicators; (2) empirical analysis of the data matrix and (3) a combination of both (Mayunga 2007). However, the assumption of a linear combination is questionable because the contribution of each indicator to the overall community resilience may not necessarily be linear. This highlights the need for an in-depth investigation of the contribution of each resilience indicator to the overall community resilience and their relative importance to the resilience of the community. However, the transferability of the outcomes of such investigations will be limited due to the disagreements in the definitions of the indicators and the measurement methods. Therefore, the immediate challenge for researchers is to build consensus in the definitions and concepts related to community resilience.

A further problem in assessing the overall community resilience using a composite indicator is the complex interaction between each of these indicators in a community setting. Further complexity arises because of the potential relationships and interactions between different thematic areas and between different key areas. For example, Adger (2000) noted that there is a clear relationship between social and ecological resilience, especially if the community depends on the ecosystem for its livelihood. This suggests that such a relationship is highly dependent on the local characteristics and a robust framework is necessary to capture such interactions. These interrelationships cascade downwards from thematic areas to key areas and then to indicators making the community resilience assessment framework a complex “network model” instead of a simple “linear model” as illustrated in *Figure 2* below.

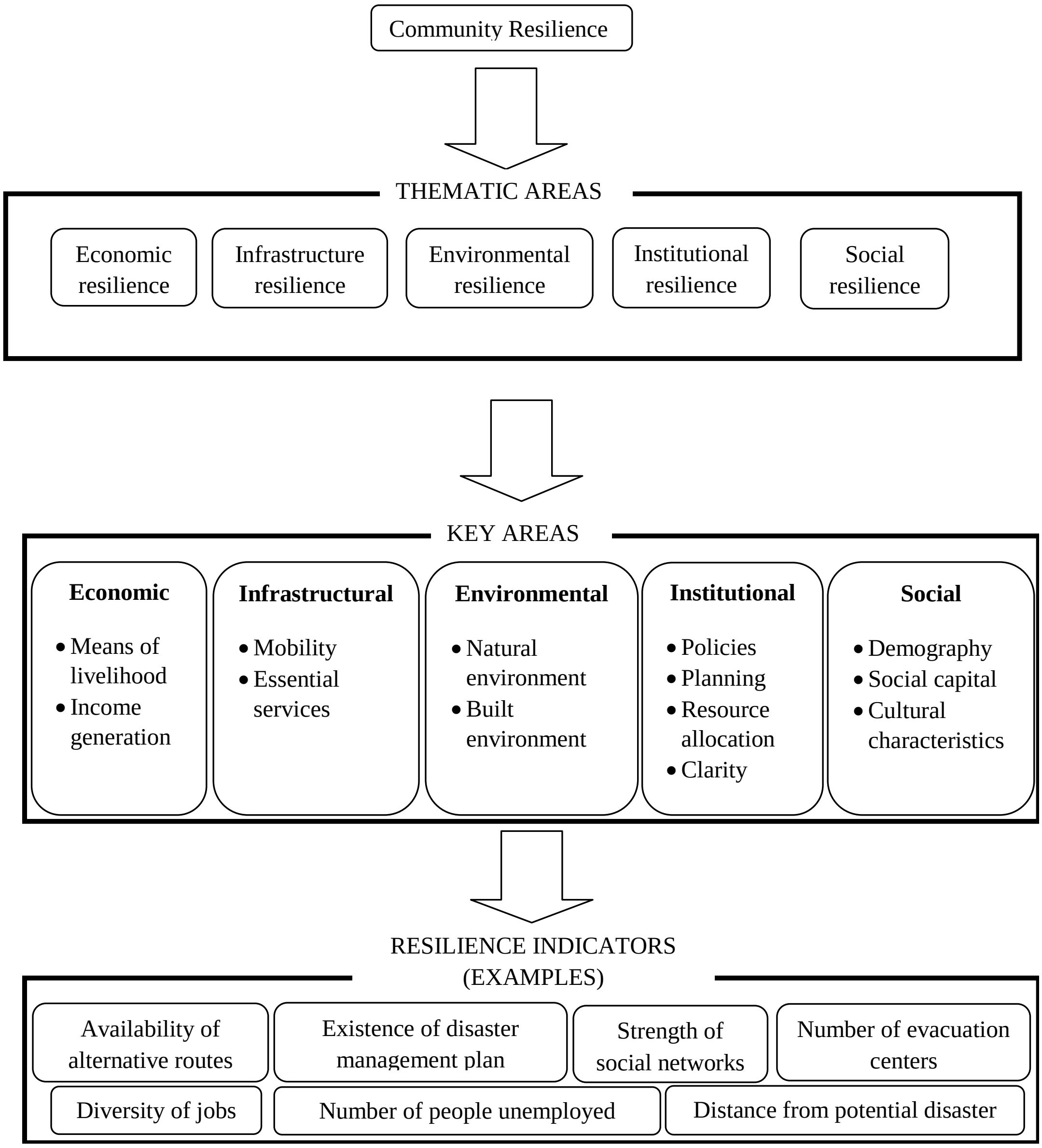

Figure 1: Framework for assessing community resilience

4. Surrogate indicators: Necessity and challenges

The model shown in *Figure 2* highlights the complexity inherent in the assessment of community resilience due to the interrelationships between thematic areas, key areas and resilient indicators. From *Figure 2*, it is evident that the complexity in assessing community resilience will increase with the number of key areas and resilience indicators required in the assessment. Consequently, it is prudent to reduce the number of key areas and resilience indicators in the assessment of community resilience. However, at the same time, the number of resilience indicators has to be adequate to comprehensively assess the resilience of a community. A possible approach is to identify a suite of surrogate indicators which can help to reduce the number of indicators and key areas required for community resilient assessment, but, at the same time, provide adequate information to comprehensively assess community resilience. This approach is scientifically viable as some indicators are correlated as illustrated in *Figure 2,* where one indicator can be represented by another, related indicator.

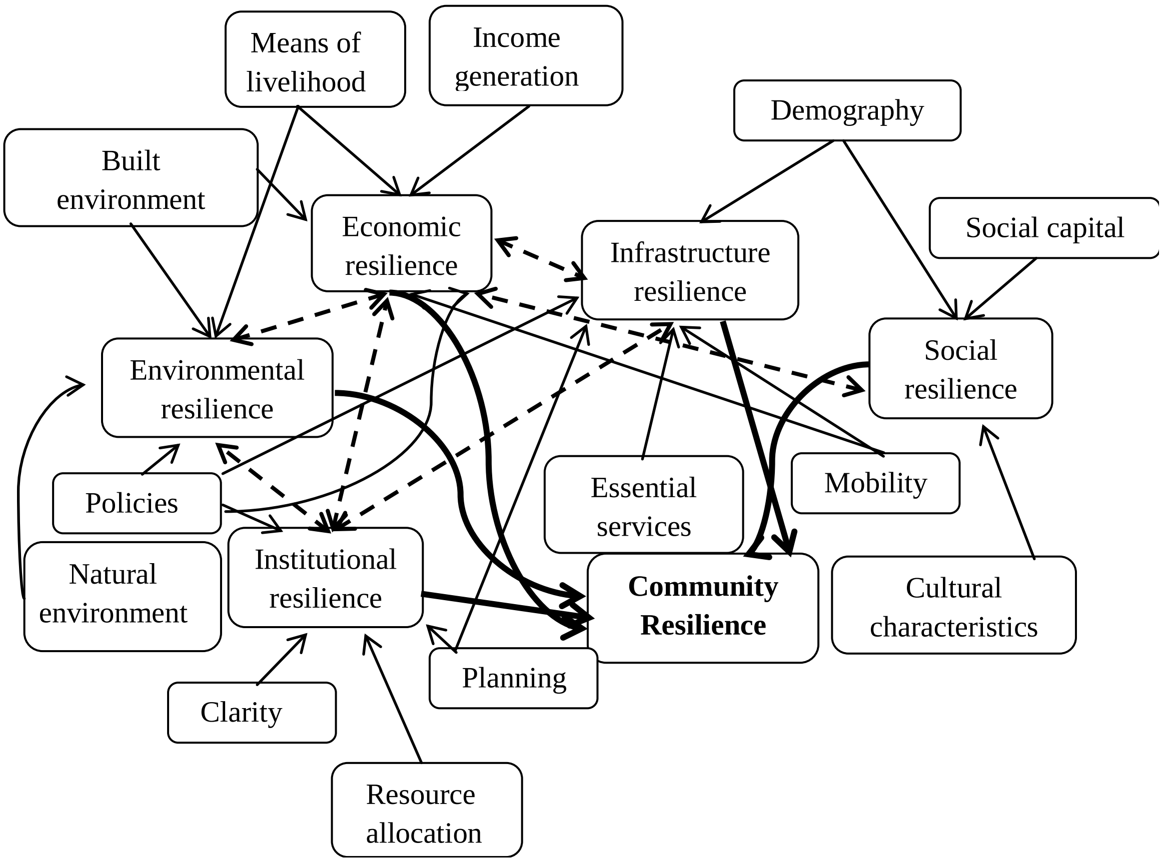

Figure 2: Hypothetical scenario to highlight the complexity of interrelationships between thematic and key areas (interrelationships between indicators are deliberately avoided to enhance the readability of the figure)

A surrogate indicator is defined as an indicator that can be used in place of another indicator or a suite of indicators and it is often more easy to measure in comparison to the initial indicator (Miguntanna et al. 2010). Surrogate indicators are widely used in day-to-day life. For example, temperature is used as the surrogate indicator for heat energy. The primary characteristic of a surrogate indicator is that it should be easier to measure to the desired degree of accuracy and it is required that the surrogate indicator can be related to the initial indicator through a relationship that can be used to predict the initial indicator (Miguntanna et al. 2010). The accuracy of the prediction depends on the accuracy of the surrogate indicator measurement and the strength of the relationship between the surrogate and initial indicators. Another important reason for the need for surrogate indicators in community resilience investigations is that some of the indicators are difficult to measure frequently, as required during continuous monitoring, compared to others.

A consequence of the difficulty in the measurement of indicators is that data collection to assess community resilience is commonly restricted to secondary data sources that are more readily available in national databases. This is because of resource and time constraints related to comprehensive and wide ranging data collection from primary data sources. For example, the criterion used by Cutter et al. (2010) for indicator selection was the availability of statistical data in national data sources such as census data.

A sole reliance on secondary data sources may provide limited assessment of community resilience as it does not take into account other community level variables such as a positive sense of the future and the strength of social networks that may influence community resilience. Consequently, the reliability of the outcomes of community resilience assessments is compromised. Therefore, it is important that indicator selection is based on a clear understanding of the type of knowledge required to comprehensively capture the resilience of the community instead of being guided by the availability of selective or easily available data.

A major challenge in the development of surrogate indicators is that the community resilience data matrix will contain both qualitative and quantitative indicators, such as, monthly income (measured in quantitative terms) and the diversity of employment (measured in qualitative terms). Hence, the approach and methods used for developing surrogate indicators should be able to handle both types of data on the same scale since it is possible for a qualitative indicator to be surrogate for a quantitative indicator and vice versa. For example, activeness of a community (measured in qualitative terms) and percentage of elderly people (measured in quantitative terms) can be surrogates for each other.

Derivation of surrogate indicators consists of two key steps: (1) the initial identification or selection of surrogate indicators and (2) their subsequent validation. It is critical to select suitable data analysis techniques for both steps to ensure the scientific robustness of the understanding developed and knowledge created. In general, common univariate data analysis technique or simple regression analysis are not sufficient for this purpose because of the complexity and relatively large size of the community resilience data matrix. Consequently, it is advisable to adopt multivariate data analytical techniques for the identification and validation of surrogate indicators.

Also, as a community resilience data matrix generally consists of a mix of qualitative and quantitative data, it is likely that the data matrix will not follow a normal distribution. Hence, the use of non-parametric methods within the suite of multivariate data analytical techniques such as Multi Criteria Decision Making methods or non-parametric correlation analysis techniques will be more appropriate for the initial identification and subsequent validation of surrogate indicators. The choice of data analysis technique will depend on the characteristics of the data matrix.

For the initial selection of surrogate indicators, it is adequate to adopt a graphical approach, in which the surrogate indicators can be determined based on the observation of correlation between the indicators such as the use of a Principal Component Analysis biplot (Settle et al. 2007). For example, in an urban stormwater quality research study, Settle et al. (2007) used multivariate data analysis technique and identified that turbidity can be used as a surrogate for suspended solids and total dissolved phosphorous, as the latter parameters are relatively harder to measure. Their decision was based on the strong correlation between the loading vectors corresponding to these parameters in a Principal Component biplot.

In contrast, the validation step requires a more rigorous approach, in which the indicators should be related to the surrogate indicators via quantitative or qualitative relationships that can be used to predict the initial indicators (Singh et al. 2012). The technique for the validation step depends on the indicator characteristics. For example, if a certain indicator has only one surrogate indicator, then a simple linear regression is adequate (Miguntanna et al. 2010). Otherwise, a complex multivariate analytical approach would be required (Mahbub et al. 2011). It is worthy to note that the strength of the relationship and the sensitivity of the surrogate indicators in predicting the initial indicator also need to be assessed to identify the strength and limitation of the developed surrogate indicators (Singh et al. 2012).

5. Application of the proposed approach: An example

This section illustrates a simple example to further explain the approach proposed above to identify surrogate indicators. For this purpose, the key area “mobility” within the “infrastructure” thematic area is selected. Under mobility, potential indicators include:

- Access to alternative routes to safe areas
- Percentage of people who own a vehicle
- Road conditions
- Diversity of mobility options
- Existence of a transport system for the mobility of people with special needs
- Existence of policies and plans for prioritising transportation resources
- Plan for mass evacuation

The first step in the surrogate indicator development is to collect data across the study area to extract information on these indicators. The data can be analysed using suitable data analysis techniques to identify the potential surrogate indicators. It is possible that the diversity of mobility option and access to alternative routes to a safe area can be surrogate to each other. This is because the area would have major roads and several small lanes and alleys leading to a relatively safe area identified by the authorities. As such, larger vehicles could make use of the major roads, while the small lanes and alleys can be used by smaller vehicles or bicycles or even for walking. This will reduce the congestion in the major roads allowing free flow of vehicles during an emergency situation. Thus, diversity of mobility options and the access to alternative routes can be surrogates to each other. In order to validate the relationship with the surrogate indicators, it is important to qualitatively or quantitatively relate them with appropriate analysis of sensitivity of such relationships. In the example given above, the surrogate and initial indicators are qualitative. Hence, the approach adopted to derive the relationship should have the ability to handle a qualitative data matrix, such as Bayesian Network Analysis (Johnson et al. 2010).

6. Conclusions

Building stronger communities with greater resilience to natural disasters is critical in current time because of the expected increase in extreme climate events and associated natural disasters. This requires a comprehensive assessment of the key factors that contribute to recovery. For this purpose, it is necessary to develop an integrated, robust and comprehensive framework for community resilience assessment.

Measurement of a wide range of resilience indicators is required for the comprehensive assessment of the resilience of a community. However, this may not be feasible in terms of resources and time. Therefore, this paper proposes the identification of surrogate indicators as a possible solution to this problem and discusses the theoretical concepts associated with the development of such indicators. The framework proposed in this study to assess community resilience consists of three data layers: (1) Five thematic areas, (2) Key areas and (3) Resilience indicators. The five thematic areas, namely, ecological, economic, infrastructural, institutional and social, are further divided into key areas, the resilience of which is measured using a comprehensive suite of indicators.

However, the thematic areas, key areas and the indicators have interrelationships resulting in a complex network model, the complexity of which increases with the number resilience indicators. Since the comprehensive assessment of community resilience requires a large number of resilience indicators, it is proposed that the identification of easy to measure surrogate indicators for community resilience assessment is a viable approach in order reduce the number of indicators without compromising on the quality of the analysis undertaken. The use of surrogate indicators can also facilitate the frequent measurement of indicators with ease thereby encouraging the researchers to use reliable primary data sources instead of relying on easily accessible, but not necessarily reliable secondary sources. The identification of surrogate indicators involves the initial selection of such indicators and their subsequent validation. The approach and techniques adopted for surrogate indicator identification and validation should be able to: (1) handle large non-parametric data matrices; (2) handle qualitative and quantitative indicators on the same scale; (3) provide quantitative or qualitative prediction relationships for an initial indicator based on the surrogate indicator and (4) provide strength and sensitivity of the prediction relationship.

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