ASSESSING REGIONAL AGROECOSYSTEM HEALTH COMBINING ECOLOGICAL-SOCIAL-ECONOMIC COMPONENTS USING CASE STUDIES OF NOVA SCOTIA AND FUJIAN PROVINCES

by

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Table of Contents

List of Tables vi

List of Figures vii

Abstract viii

List of Abbreviations Used ix

Acknowledgements x

Chapter 1 INTRODUCTION 1

1.1 Background and Problem Statement 1

1.2. Cross-National Context 3

    1.2.1 Canadian Agroecosystem 3

    1.2.2 Chinese Agroecosystem 5

1.3. Agroecosystem Health Theory 8

    1.3.1 Agroecosystem Health Theory Development in Canada 8

    1.3.2 Agroecosystem Health Theory Development in China 10

1.4 Research Objectives 12

1.5 Thesis Structure 13

Chapter 2 AGROECOSYSTEM HEALTH AND AGROECOSYSTEM MANAGEMENT 15

2.1 Introduction 15

2.2 Understanding Agroecosystem Health 17

    2.2.1 Agroecosystems 17

    2.2.2 Agroecosystem Health 19

    2.2.3 Agroecosystem Health Components and Indicators 21

2.3 Linking Agroecosystem Health and Agroecosystem Management 21

2.4 Conceptual Framework for Sustainable Agroecosystem Management 23

    2.4.1 Farm scale 23

2.4.2 Watershed Scale 24

2.4.3 Global Scale 25

2.5 Conclusion 26

Chapter 3 A SINO-CANADIAN COMPARATIVE STUDY OF EXPERTS' PERCEPTIONS TOWARDS AGROECOSYSTEM HEALTH 29

3.1 Introduction 29

3.2 Data and Methods 31

3.2.1 Study Design 31

3.2.2 Selection of Participants 32

3.2.3 Surveys and Questionnaires 32

3.2.4 Data Collection and Analysis 33

3.3 Results 33

3.3.1 Response Rates 33

3.3.2 Identification of Agroecosystem Health Indicators 34

3.3.3 Rankings of Agroecosystem Health Indicators 35

3.4 Discussion 36

3.4.1 Difference and Similarity between Canadian and Chinese Experts 36

3.4.2 Difference and Similarity among Academic Discipline Groups 38

3.4.3 Limitations and Application 39

Chapter 4 MEASURING THE HEALTH COMPONENTS OF AGROECOSYSTEMS IN SPACE: AN EMPIRICAL EXPLORATION USING GIS 44

4.1 Introduction 44

4.2 Overview of Selected Agroecosystem Health Indicators 46

4.2.1 Selected Ecological Indicator - Soil Erosion 46

4.2.2 Selected Economic Indicator - GDP 47

4.2.3 Selected Social Indicator - Self-Perceived Human Health and Happiness 47

4.3 Data and Methods 48
    4.3.1 Study Areas 48
    4.3.2 Soil Erosion Measurement 51
    4.3.3 Economic Indicator - Purchasing Power Parity GDP 55
    4.3.4 Human Health and Happiness 57
    4.3.5 Geospatial and Statistical Analysis 59
4.4 Results 60
    4.4.1 Spatial Variation in Agroecosystem Health Indicators in Nova Scotia 60
    4.4.2 Spatial Variation in Agroecosystem Health Indicators in Fujian 63
4.5 Discussion 65
    4.5.1 Exploiting GIS in Agroecosystem Health Evaluation 66
    4.5.2 Spatial Changes in Agroecosystem Health Indicators 66
    4.5.3 Implications and Limitation 69
Chapter 5 EMPIRICAL EVALUATION OF AGROECOSYSTEM HEALTH COMBINING ECOLOGICAL-SOCIAL-ECONOMIC COMPONENTS: A COMPARISON BETWEEN NOVA SCOTIA AND FUJIAN 72
5.1 Introduction 72
5.2 Data and Methods 75
    5.2.1 Selected Agroecosystem Health Indicators 75
    5.2.2 Geospatial Analysis 81
    5.2.3 Generation of Agroecosystem Health Index 81
    5.2.4 Statistical Analysis 82
5.3 Results and Discussion 83
    5.3.1 Comparing Agroecosystem Health between Nova Scotia and Fujian 83
    5.3.2 Spatial Distribution of Agroecosystem Health 90
5.4 Conclusion 95

Chapter 6 CONCLUSION 98

6.1 Introduction 98

6.2 Findings with regard to the Research Questions 98

6.3 Novel Contributions to Science and Implications 102

    6.3.1 Theoretical Contributions 102

    6.3.2 Methodological Contributions 103

6.4 Limitations and Recommendations 105

References 108

Appendices 127

Appendix A 127

Appendix B 136

List of Tables

Table 3.1 Rankings of selected indicators to assess agroecosystem health by Chinese and Canadian experts 41

Table 3.2 Chi-Square analysis of nationality and specialty groups of rankings of indicators selected by both Chinese and Canadian experts 43

Table 4.1 Zonal statistic for selected indicators in Nova Scotia 61

Table 4.2 Zonal statistic for selected indicators in Fujian 64

Table 5.1 Comparing agroecosystem health indicators across regions between Nova Scotia and Fujian........83

Table 5.2 Temporal changes of regional agroecosystem health indicators in Nova Scotia........83

Table 5.3 Temporal changes of regional agroecosystem health indicators in Fujian......84

List of Figures

Figure 2.1 Conceptual framework for sustainable agroecosystem management............. 26

Figure 4.1 Study areas for analysis of agroecosystem health 49

Figure 4.2 Rural and urban areas in Nova Scotia – based on population density: 2006 . 50

Figure 4.3 Rural and urban areas in Fujian - 2010 50

Figure 4.4 **a.** Spatial variation in the rainfall erosivity factor (R) in Nova Scotia; **b.** Spatial variation in slope length factor (L) in Nova Scotia; **c.** Spatial variation in slope steepness factor (S) in Nova Scotia; **d.** Spatial variation in soil erodibility factor (K) in Nova Scotia; **e.** Spatial variation in cover management factor (C) in Nova Scotia; **f.** Spatial variation in support practices factor (P) in Nova Scotia...................................... 54

Figure 4.5 **a.** Spatial variation in the rainfall erosivity factor (R) in Fujian; **b.** Spatial variation in slope length factor (L) in Fujian; **c.** Spatial variation in slope steepness factor (S) in Fujian; **d.** Spatial variation in soil erodibility factor (K) in Fujian; **e.** Spatial variation in cover management factor (C) in Fujian; **f.** Spatial variation in support practices factor (P) in Fujian.. 55

Figure 4.6 **a.** Spatial variation in the estimated rate of soil erosion in Nova Scotia; **b.** Spatial variation in GDP per head in Nova Scotia; **c.** Spatial variation in human health in Nova Scotia; **d.** Spatial variation in human happiness in Nova Scotia............................ 62

Figure 4.7 **a.** Spatial variation in the estimated rate of soil erosion in Fujian; **b.** Spatial variation in GDP per head in Fujian; **c.** Spatial variation in human health in Fujian; **d.** Spatial variation in human happiness in Fujian 65

Figure 5.1 Agroecosystem health indicators and agroecosystem health in Nova Scotia (normalized).. 92

Figure 5.2 Agroecosystem health indicators and agroecosystem health in Fujian (normalized).. 93

Abstract

There is growing interest in the theory and methods for assessment of agroecosystem health because of the realization that these approaches have the potential to better inform management strategies. Despite this growing attention, there continues to be a lack of scientific basis for an integrated (ecological-social-economic) assessment of agroecosystems on a larger scale and in a global context. This project established a framework for agroecosystem health assessment that integrated ecological, social and economic components. Nova Scotia and Fujian Provinces were utilized as contrasting geographic and political regions to test the framework and demonstrate its usefulness for regional evaluation of agroecosystem health. In order to develop frameworks for agroecosystem evaluation, experts with diverse academic backgrounds both in Canada and China were invited to identify and rank agroecosystem health indicators. While there was good agreement among experts in most areas, the analysis showed some significant differences in the perceptions towards agroecosystem health indicators between Canadian and Chinese experts. Soil erosion, gross domestic product (GDP) and human happiness and health, were jointly selected as the primary agroecosystem health indicators from the perspectives of ecology, economics and sociology, respectively. Geographic information system (GIS) analysis was applied to explore and present both spatial and temporal changes of these three primary indicators in the two regions. These three health indicators were considered together, to develop an overall agroecosystem health assessment comparing Nova Scotia and Fujian. The results indicated that Nova Scotia had a significantly higher level of agroecosystem health, compared with Fujian, using health integrity index combining soil erosion, GDP per head and self-reported human happiness and health. This dissertation provides a methodological approach using multiple criteria analysis based on GIS to demonstrate how to conduct interdisciplinary research for agroecosystem assessment. This study has potential to contribute to current understanding of agroecosystem assessment and management, which is needed by policy and decision makers.

List of Abbreviations Used

C	Cover management factor
CGSS	Chinese General Social Survey
CCHS	Canadian Community Health Survey
DEM	Digital Elevation Model
ESA	European System of Accounts
IWM	Integrated Weed Management
FAO	Food and Agriculture Organization
FM	Modified Fournier Index
GDP	Gross domestic product
GIS	Geographic information system
JAXA	Japan Aerospace Exploration Agency
K	Soil erodibility factor
LS	Slope length and slope steepness factor
MEA	Millennium Ecosystem Assessment
NS	Nova Scotia
NASA	National Aeronautics and Space Administration
OER	Official Exchange Rate
P	Support practice factor
PPP	Purchasing Power Parity
R	Rainfall erosivity factor
RS	Remote Sensing
TRMM	Tropical Rainfall Measuring Mission
SRTM	Shuttle Radar Topographic Mission
US	United States
WHO	World Health Organization

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CHAPTER 1 INTRODUCTION

1.1 Background and Problem Statement

There is increasing evidence that growing variety and intensity of human activities, especially for agricultural practices, have greatly changed ecosystems over the past century (Ceballos *et al*., 2015; National Research Council, 1991; Vitousek *et al.*, 1997). The recent great gains in agricultural yields comes at the cost of the sacrifices of other services and benefits provided by the ecosystems, especially clean water and productive soil; this is accompanied by a substantial degradation of the global environment (Olsson and Ardö, 2002; Bakr *et al*., 2012; Foley *et al*., 2011; El-Sharkawy, 2014; Crosson and Anderson, 2014). A further increase in agricultural production is essential to feed the growing world population in the future. Therefore, sustaining agricultural production while optimizing the status of environment has been one of the major challenges for farmers, researchers and policymakers (Tilman *et al.*, 2002; Bohlen and House, 2009; Tscharntke, 2012).

It has become evident that a more holistic and multidisciplinary approach is required to understand the relationships between human activities and environment that are involved in agriculture (Rapport, 1995). Considering agriculture's multi-functionality, Agroecology is regarded as a discipline that integrates various approaches from agronomy, ecology, sociology and economics (Dalgaard, Hutchings, & Porter, 2003). An agroecosystem is the basic study unit for Agroecology. As a spatially and functionally coherent unit related to agricultural activity, an agroecosystem includes the living and nonliving components involved in that unit, as well as their environment and interactions (Conway, 1984; Smit *et al*., 1998). Agroecosystems may be described narrowly as small-scale farming systems, or in a broader context as communities or watersheds, or more broadly on a regional or even global scale (Conway, 1986; Altieri, 1999; Bohlen and House, 2009). Agroecosystems are ecological-social-economic systems that are strongly influenced and controlled by human activities. Agroecosystems are characterized as having both ecological and socio-economic components, which affect their overall performance and productivity (Conway, 1987; Marten, 1988). The agro-ecological research uses systematic analysis tools to evaluate agroecosystems and identify best management strategies to maintain the sustainability of agroecosystems (Brym & Reeve, 2016).

The introduction of a "health" concepts into agroecosystem research has stimulated growing interest among scientist community concerning the long-term sustainable development of agriculture (Xu & Mage, 2001). Agroecosystem health is a notion as an agroecological concept for analyzing and managing agroecosystems (Yiridoe & Weersink, 1997; Xu & Mage, 2001; Altieri & Nicholls, 2003; Vadrevu *et al*., 2008; Zhu *et al*., 2012). Research on agroecosystem health has been aroused by a desire to assess their condition, to understand the process and the structure in a greater depth, and to identify how health status of agroecosystem can be improved (Waltner-Toews (1994). There is a growing recognition by the scientific community that the research on agroecosystem health which enables systematic assessment of agroecosystems using a multidisciplinary approach can assist in overcoming the challenges of agroecosystem management in a sustainable way (Yiridoe & Weersink, 1997; Liebig *et al*., 2001; Andrews & Carroll, 2001; Gitau *et al*., 2008; Bachev, 2009, 2010; Zhu *et al*., 2012). It is believed that improvement of the availability of information about health of agroecosystem and integrate this information into agricultural policy and decision making are essential (Bingham *et al*., 1995; Liebig *et al*., 2001, Bachev, 2009, 2010; Zhu *et al*., 2012; Plieninger *et al*., 2012). Frameworks and indicators have been proposed as measurements to evaluate the status of an agroecosystem at multiple scales (Smit *et al.*, 1998; Xu & Mage, 2001; Altieri & Nicholls, 2003; Vadrevu *et al*., 2008; Su *et al*., 2012; Peterson *et al*., 2017).

Interest in agroecosystem assessment and analysis is growing; however, few studies have been conducted on a large-scale assessment of agroecosystem health that integrated ecological-social-economic components. In addition, difficulty in establishing a uniform systematic and scientific evaluation index system has become the bottleneck of agroecosystem health research (Zhu *et al*., 2012). Some studies attempt to apply a framework to evaluate agroecosystem health, but lack clear illustrations of how the agroecosystem health indicators are selected and used (Yiridoe & Weersink, 1997). Moreover, attitudes toward agricultural ecosystems health in cross-cultural comparisons have rarely been documented. Moreover, few research has compared agroecosystems among different regions or countries in space and time in a global context.

The provinces of Nova Scotia (Canada) and Fujian (China), as two coastal provinces from developed and developing countries respectively, have different levels of overall economic development, different cultural values, political and social systems. There are, however, similarities between the two provinces, notably in pleasant climate, high forest coverage rates, abundance of natural resources and multi-biodiversity. This study used Fujian and Nova Scotia as case studies to provide empirical exploration that incorporated a multi-disciplinary approach to assess agroecosystem health at a provincial scale within a global context.

1.2. Cross-National Context

Agroecosystems are characterized as having ecological and social-economic dimensions (Okey, 1996). The adoption of a systematic approach to the model of agroecosystem health has led to the need for understanding of the context of the two case studies, from the ecological, social-economic, political system aspects.

1.2.1 Canadian Agroecosystem

Canada is well endowed with a natural environment that provides a good foundation for agricultural development (biodivcanada.ca). Canadian agricultural lands cover 7% of the land area (Agriculture and Agri-Food Canada, 2014). The Canadian agroecosystem is characterized by modern and advanced technology, high complexity and intergradation, and international competitiveness. The Canadian agricultural system is considered to be a resilient system with a goal to attempt to respond to the opportunities and challenges it faces related to changing demands of consumers, advancing technology and globalization (Agriculture and Agri-Food Canada, 2014).

Since 2007, agriculture's contribution to the Canadian GDP has increased annually. According to a report on the Canadian Agriculture and Agri-Food System released in 2014, the wealth created by Canada’s agriculture industry was $103.5 billion, accounting for 6.7% of Canada's GDP in 2012 (Agriculture and Agri-Food Canada, 2014). Simultaneously, it was reported that approximately 50% of the value of Canadian agriculture production is exported, and the processed foods industry is especially dependent on exports.

The Canadian economy is uniquely dependent on its natural resource exploration (MacArthur, 2014). The natural resources include oil, forest, minerals, fur, coal, minerals, fish and other recourses. With a relatively small population, Canada processes the largest land masses and quantities of natural resources, which grants Canada an advantage in wealth generation, compared with other countries (Hessing & Summerville, 2014). On the other hand, Canadian agroecosystems are affected by a variety of factors, including air pollution, deforestation, wildlife habitat depletion, water pollution, as well as the effects of residential solid waste, industrial waste, and soil degradation. These problems lead to disorder of the ecosystem structure and threaten agroecosystem services, and long-term sustainability (Hughes, 2011).

The environmental awareness and concern had increased throughout North America since the first half turn of the 20th century when the negative impact of human settlement and industrial expansion was becoming more apparent (Parkins, 2006). The environmental problems have gradually been debated as a serious national public policy issue. In 1969, the first piece of national environmental legislation - the Canada Water Bill was passed, which was the milestone of the environmental policy-making in Canada. Federal and provincial governments have been pressured to establish and implement new environmental laws, act and assessment process to respond to increasing ecological disasters and degradation (Hillyard, 1995). As well, environment-oriented departments and agencies were established, such as Environment Canada. The participatory approach to policy development has been playing an essential part in the environmental management practices in Canada (Parkins, 2006). One of the most influential environmental programs implemented Canadian governments that have been ongoing in Canada for a number of years, both formally and informally, is the environmental assessment strategy (Noble, 2009). As Noble (2009) noted, however, the strategy is lacked from consolidation in scope and function, and had limited methodological guidance and institutional support that is essential for suggesting policy for next level. Gibson *et al.* (2015) indicated that the laws and practices of environmental assessment in

Canada had not achieved the initial goal of integrating habitual attention to environmental concerns.

Canada has a relatively superior social support system to that of China. Since Canada is a federal state, theoretically, each level of government has exclusive authority to enact legislation in policy areas such as healthcare, social welfare and education (Béland & Lecours, 2005). Provinces provide publicly funded healthcare, elementary or secondary school education, with some of the costs partially subsidized by the federal government and a small percentage of the cost are under private sectors. Therefore, members of the society can access free medical health care. Seniors can get old-age pensions, and low-income individuals and families can obtain social assistance and support (Armitage, 2003). There are also different social organizations providing social services designed to support children, youth, the elderly, and the physically disabled individuals. However, there has been a cutback in state expenditure, from both federal and provincial governments, in social services, in recent years, which may affect social welfare and social services in Canada. Complaints arose that the economic system cannot function with the increased taxation to support social programs (Rice, & Prince, 2013).

1.2.2 Chinese Agroecosystem

China is a country with more than one-fifth of the world's population and limited resources per capita, so as the population has grown, agriculture has played an increasingly key role in China. China's agricultural output ranks first in the world, but the cultivated land (about 1.4 million square kilometers) only accounts for 15 % of its total land area (Sattari *et al*., 2014). Only about 1.2 % (116,580 square kilometers) of this cultivated land permanently supports crops (Saxena, 2013). In 1978, more than 60 % the population made their living directly from farming, but this decreased to 26 % in 2007. According to the World Bank (2014), the percentage of gross domestic product (GDP) that agricultural production contributes in China decreased from 42.15 % in 1960 to 9.17 % in 2014.

Over its long history, China has accumulated a wealth of experience and knowledge on agricultural techniques and systems. Characteristics of agroecosystems related to cultivation, production, organization, marketing, and consumption, have been formed within China's unique cultural-historical background, economic-social circumstances, as well as ecological and natural conditions (Wei & Tan, 1995; Li, 2001). Remarkable achievements in agricultural development have been realized, particularly since 1978 after the reform of Chinese Agricultural economic system (Gulati & Fan, 2007). In 1995, in the book "Who Will Feed China?" Brown noted that China would soon need to import a great deal of grain to feed its 1.2 billion and increasing population. This could have triggered unprecedented rises in world food prices; however, in recent years, the rate of food self-sufficiency in China has risen to 97%, consistent with past food self-sufficiency rates (Li *et al*., 2013). The fact that China, with only about 7% of the world's cultivated land supports 22% of the global population (Yu *et al*., 2013) refutes the Chinese food shortage threat postulated by Brown (1995).

The economy has been developed rapidly to meet the increasing demands of growing population for improving human well-being. However, this unprecedented development, along with fast urbanization and industrialization process, has been accompanied by severe environmental problems (Yu, 2014). Environmental issues, including limited land resource and the increasing population, soil degradation and soil erosion, air and water pollution, global warming, the lack of energy and natural resources, are hindering the sustainable development of agriculture and agroecosystem maintenance. Environmental degradation in China has raised serious concerns about the hidden costs of economic growth (Yu, 2014).

The Chinese government has gradually recognized that China was experiencing a deep and persistent environmental crisis that, in turn, led to serious economic losses, public health problem and other social problems within China. The government is trying to tackle the environmental crisis (Liu & Diamond, 2005). The Environmental Protection Act of the People's Republic of China was legislated in 1979, with rapid acceleration in the 1990s when a series of environmental laws, executive regulations, standards and measures were issued (Mol & Carter, 2006). Along with recent five-year plans that emphasized the importance of environmental protection in its national development strategy, China has made progress in reducing air pollution and greenhouse gas emissions (Liu *et al*., 2012). However, Liu *et al*. (2012), also stated that the effective pollution control could not be achieved unless China's government made further progress in the enforcement of environmental laws. It is known that there is a gap between legislation and implementation of the environmental protection in China (Chan *et al*., 1995). In the Chinese context, local governments are the political units which implement the policy and act. However, existing environmental laws are sometimes ignored by local government leaders since they were seen as working against economic development (Liu & Diamond, 2008).

As well, China is still in the formative stages of industrialization and modernization. Massive changes are currently taking place in Chinese society where massive migration from rural areas to cities occurred every year since the 1990s (Yu *et al*., 2014). The urbanization and urban development have generated wealth and increased human wellbeing; however, in the short-term, they also bring negative effects on the whole society. The uneven development between urban and rural areas for the economic developments and social supports has been aggregated (Han, 2014; Han & Huang, 2017). It is it known that rural populations in China are poorer and less well educated than urban populations (Yu *et al*., 2014). Treiman (2012) pointed out that rural-urban disparities in economic and social development, especially regarding income and human well-being, remain substantial in China. This divergence is largely due to the rural-urban registration system in China. A person who has a non-rural household registration can access more educational and medical resources, job opportunities and social welfare, compared with those who have rural household registration status (Treiman, 2012). Moreover, local food insecurity and an incomplete social welfare system, as well as low coverage support from public social, medical insurance and seniors pension, cause an accumulative insecurity especially in special rural subsets of the population in China. Efforts have been made to increase the uniform provision of senior and public medical services, but it requires considerable time to ensure every resident in Chinese society has access to public medical health insurance and have enough money to support themselves when one gets old.

Identifying ways to overcome these problems has become a critical issue in China. Research on the evaluation and management of agroecosystems, and on how the environmental and social-economic components change in time and space is extremely crucial in China and has been regarded as an essential step towards developing a better understanding of conditions of the agroecosystem and the links between agroecosystem changes and agricultural activities.

1.3. Agroecosystem Health Theory

1.3.1 Agroecosystem Health Theory Development in Canada

The agroecosystem health theory in Canada was developed in North American countries in the 1960s and 1970s (Conway, 1986, 1987). This theory is primarily characterized by the practices of ecological agriculture and organic farming. When human activities are involved with resource industries (i.e., fishing, agriculture, forestry, and mining) without constraints or protections, the surrounding environment may be degraded and the services provided by the ecosystem reduced. To feed a growing need from the population without causing environmental degradation, attention must turn to those ecological agricultural practices that have the potential to maintain optimum productivity over time (Allen & Van Dusen, 1988; Gitau *et al*., 2008). Applied terms, sustainability and health in an ecological context, describe methods for provided tools for systematic diagnosis and treatment of agricultural practices and agroecosystems (Waltner-Toews, 1996; Gitau *et al*., 2008). Such approaches have advanced new ways of perceiving the relationship between human activities and environmental changes. The research on agroecosystem analysis has been advancing since the concept of health of the whole environment was applied to the dimensions of agroecosystems, generating innovative perspectives in this field.

In 1990, a new and interdisciplinary program, called the Eco-Research Program of the Tri-Council of Canada, was funded as part of the national Green Plan in Canada. One of the ecological projects in this program was the Agroecosystem Health Project at the University of Guelph. The project aimed to provide a framework for the assessment and improvement of the health of agroecosystems. A global network, which focused on agroecosystem health, was established at Guelph University in 1994. This network included Canada, Peru, Kenya, Nepal, Ethiopia and Honduras; it supplied a platform for sharing information and communication. Canadian researchers from many disciplines participated in this research, and the impact of this study extended from local to national and global levels (Waltner-Toews, 1996). One of the main features of the concept proposed by Waltner-Toews is that agroecosystem health provides a comprehensive and holistic basis for assessing the condition of rural farming environments and communities.

Okey (1996) proposed that characteristics of a healthy agroecosystem include the balance of stability (multiple states) and resilience, the diversity /complexity maintained, the intrinsic value of wildlife, the aesthetic value of landscapes, equitability in distribution of goods and services among rural population, and the balance of economic and ecological efficiency. Other authors suggested a conceptual framework linked the general components of Integrated Weed Management (IWM), including soil and ground cover management, crop and nutrient management, as well as modeling, to agroecosystem health (Swanton & Stephen, 1996). From the perspectives of agricultural land use, Xu & Mage (2001) presented and tested a conceptual framework for assessing the changes in agroecosystem health in the context of dynamic relationships in agroecosystems, using southern Ontario and Wellington County as case studies. In these two case studies, the changes associated with different processes of land use conversion and their association with agroecosystem health were examined. In 1998, Smit *et al.* published the book entitled Agroecosystem Health, Analysis and Assessment which defined agroecosystem health and established a framework for its evaluation. They proposed that agroecosystem health refers to the condition, state, or capacity of an agroecosystem. According to Gitau *et al*. (2008), an agroecosystem health perspective provided methodologies for studying the relationship between human health and well-being issues and agroecosystem ecological sustainability within a tropical agroecosystem. One of the typical characteristics of their writing is that they illustrated how community participation methods and soft system methods[1] were employed in agroecosystem health research. In addition, they integrated the agroecosystem health and sustainability

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[1] Soft System Method is a method used for organizational process modeling (business process modeling). It can be utilized both for general problem solving as well as the management of change. It was developed in England through a ten year action research program by academics in Systems Department at the University of Lancaster (Wilson and van Haperen, 2015).

concerns into the practical decision. Later, Orozco and Cole (2012) extended this work by taking an ecosystem approach to health in two Ecuadorian provinces with larger indigenous populations and agroecosystems. They aimed to tackle an understanding of the multiple drivers of inappropriate use of pesticides with the long-term goal of greater agroecosystem sustainability, including better human health.

Regarding ecological and environmental attitudes and values, the emerging and expanding eco-centric values play a major role in the Canadian population mindset. Canadians have started to realize the importance of ecosystem and environment protection. These values were learned from more than one hundred years of industrial development with regards to the cost of environmental pollution and ecological problems. Scholars also started to realize the importance of engaging directly in regulatory and litigation processes in environmental protection (MacLean & Tollefson, 2015). At the same time, the individualistic culture which is more dominant in Canada than some other countries has important effects on the formation of environmental values (Dheer *et al*., 2014).

1.3.2 Agroecosystem Health Theory Development in China

Chinese ecological theory, which originated thousands of years ago, is focused on the harmony of humans and nature. This principle was advocated and canonized by Confucianism, Taoism, and Buddhism, and has exerted a long and lasting influence on the attitudes of the Chinese and Chinese history. In China, the concept of ecological agriculture was originally proposed in the first national academic seminar of agricultural ecological-economics by Chinese scholar (Ye, 1988). Ecological agriculture in China focuses on a combination of pollution control and utilization of resources. Ecological agriculture aims to maximize the economic benefits while minimizing environmental impacts. In 1997, researchers started to realize that ecological agriculture should be regarded as the key aspect required for long-term economic and social development in China (Wu *et al*., 2001). Knowledge and insight into environmental conditions for agriculture have been used to inform and guide agricultural policy-making. In the late 90s, inspired by modern systems theory, the ecological agriculture model was expanded from the farm level to include communities and watersheds, thus creating an agroecosystem health approach. Since 2000, agroecosystem health, as a relatively new term introduced from western countries, has been drawing increased attention in China.

Wang and Shen (2001) provided an overview of the international research on agroecosystem health, briefly introducing the features of agroecosystem health theory and giving information on its formation, and development over time. Stress factors, which endanger the health of agricultural ecosystems, as well as widely used methods and indices for agroecosystem health evaluation, were identified and addressed. Li and Chen (2003) analyzed the relationships between agroecosystem health and human health, suggesting that the agroecosystem health theory plays an essential role in ecological agricultural development, as well as in human survival and social development. Using Yucheng City in Shandong Province in China as a case study, Wu, Ouyang, and Tang (2004) illustrated how the health status of an agroecosystem could be evaluated using an integrated evaluation index system. Zhao (2004) and Wang &Wei (2006) further advanced the research of agroecosystem health evaluation, by using the Weihai agroecosystem in the Shandong and Gansu Provinces in China as case studies. In 2012, a geospatial framework for agroecosystem health evaluation was proposed by Su *et al.* (2012). By combining remote sensing (RS) and geographic information systems (GIS), this framework has the potential to be applicable to many landscape scales with similar conditions. In 2012, Zhu *et al*. reviewed the development of agroecosystem health research and addressed the approaches and criteria for agroecosystem health assessment. Pathways of agroecosystem management from a holistic dimension were proposed. The concept of agroecosystem health has been put forward as a scientific basis for making policy decisions and formulating new plans in agricultural development.

However, Chinese theories of agroecosystem health may still be in the initial stages of elaboration; there is a long way to go before the public and policymakers accept this approach and put it into practice. With respect to the values and attitudes of the Chinese population, one of the characteristics that affect Chinese attitudes is the norm of collectivism. According to Hofstede (2001), persons in collectivist societies learn to respect the group to which they belong and typically pursue the objectives of the groups, focusing on the benefits to their units or nations. Therefore, it is more likely for them to consider their individual goals and benefits as secondary to the goals of the group, compared to people from countries dominated by individualism. Chinese culture is characterized by a focus on man's harmony with the ecosystem and in the ancient philosophical belief in the "unity of man and nature" (heaven); however, according to Fox & Vogler (2005), nature has been greatly impacted by human activities. The traditional theory, which appreciates man's harmony with nature has been challenged, to some degree, as a result of the disconnection between human needs and limited natural and land resources.

1.4 Research Objectives

The goal of this research is to establish an integrated (ecological-social-economic) framework for agroecosystem health evaluation on a larger scale within a global context.

RESEARCH QUESTIONS

1. How can agroecosystem health be measured, combining ecological-social-economic components?
2. Are there significant differences in the level of agroecosystem health between Nova Scotia and Fujian provinces?

HYPOTHESES

1. There are significant differences in the perceptions towards agroecosystem health indicators between Canadian and Chinese experts;
2. GIS can be used as a tool for agroecosystem health assessment, combining ecological-social-economic components;
3. There are significant differences in the level of agroecosystem health between Nova Scotia and Fujian provinces.

SPECIFIC RESEARCH OBJECTIVES

1. To establish an integrated (ecological-social-economic) framework for agroecosystem health evaluation on a larger scale (Chapter 3);
2. To use Nova Scotia and Fujian provinces as contrasting geographic and political regions to apply the framework and evaluate both spatial and temporal changes of agroecosystem health, from the perspective of ecology, economics and sociology (Chapter 4 and 5);

3. To compare agroecosystem health combining ecological-social-economic components between Nova Scotia and Fujian (Chapter 5).

1.5 Thesis Structure

In Chapter 2, a literature review addresses the concepts of agroecosystem health and the relationship between agroecosystem health and agroecosystem management. This chapter provides a theoretical basis for the whole thesis.

Chapter 3 first develops an integrated (ecological-social-economic) framework for agroecosystem health based on a survey conducted in both Canada and China. The differences and similarities in the perceptions of agroecosystem health, between Canadian and Chinese experts and among three groups of agricultural specialists, were compared. The primary health indicators jointly suggested by both Canadian and Chinese experts are obtained from this survey for further empirical studies in this research.

Chapter 4 presents an empirical study to explore agroecosystem health from the perspectives of ecology, economics and sociology on a provincial scale in a global context. This chapter demonstrates the application of geographic information system (GIS) combining remote sensing data and census data to monitor ecological, social, economic components of agroecosystem health on a large scale in a global context. Based on the rankings of jointly identified indicators from Chapter 3, three key indicators were selected from ecological, economic and social aspects. Using Nova Scotia and Fujian provinces as case studies, this chapter investigates spatial variation of three key agroecosystem health components/indicators across scales (provincial and sub-regions).

Chapter 5 presents a comparison of agroecosystem health combining ecological, social and economic components between Fujian and Nova Scotia. The three health components/indicators from Chapter 4 are normalized and then aggregated into one integral assessment of agroecosystem health. The differences in the levels of agroecosystem health components and generated agroecosystem health index are compared between Nova Scotia and Fujian. GIS is utilized to visually present the spatial changes in the normalized variables and the final agroecosystem health index in the two case studies.

Chapter 6 concludes the thesis with a summary of the research findings in relation to the research questions and hypotheses, and the novelty of the research, as well as the implications and suggestions for future research.

CHAPTER 2 AGROECOSYSTEM HEALTH AND AGROECOSYSTEM MANAGEMENT

2.1 Introduction

Agroecosystems are spatially and functionally coherent units of agricultural activity which include the living and nonliving components involved in these units as well as their interactions in a social-economic context (Okey, 1996; Smit *et al*., 1998). Agroecosystems are not self-sustaining as they rely on both internal and external inputs, and are closely associated with agricultural activities. The definition of an agroecosystem is not restricted to specific farm units, but rather include the communities, watersheds and regions that are impacted by the agricultural activity (Okey, 1996; Vadrevu *et al*., 2008; Zhu *et al*., 2012). There is abundant evidence that agricultural practices have greatly changed agroecosystems over the past century (MA, 2005). These practices have created gains in agricultural yields; however, they come with a cost such as the loss or reduction in other services and benefits provided by the agroecosystems, including clean water and productive soil. The impacts of the changing agricultural practices have resulted in a substantial overall degradation of the global agroecosystem (Olsson & Ardö, 2002; MA, 2005; Bakr *et al*., 2012; Foley *et al*., 2011; El-Sharkawy, 2014; Crosson and Anderson, 1999). Therefore, sustaining agricultural production while conserving the services and avoiding the degradation of an agroecosystem poses a huge challenge in agroecosystem management (Bohlen & House, 2009; Tscharntke *et al*., 2012). It has become evident that a more holistic, multidisciplinary approach is required in agroecosystem management to realize these potentially competing objectives (Rapport *et al*., 1995).

Interest in ecosystem health has increased among ecologists who are aware of the threats to the sustainable development of this planet and life living on it. The concept of ecosystem health goes back to 1788 when a Scottish physician proposed that the earth is a super-organism capable of self-maintenance (Hutton, 1788). GAIA theory, which was proposed by in the 1960s by Lovelock, takes Earth as one of the complex processes that maintain conditions suitable for life. The complex entity involving the Earth's biosphere, atmosphere, oceans, and soil constitute a feedback or cybernetic system which pursues an optimal physical and chemical environment for life on this planet (Lovelock, 2000). The naturalist, Aldo Leopold (1941) further developed the concept of ecosystem health by introducing the ‘land health’ perspective to ecosystem considerations. He indicated that the key indicators for land sickness and degradation include soil erosion, loss of soil fertility, the decrease and extinction of some species, the outbreak of pest and diseases, and overall reduction agricultural productivity. Rapport suggested that like all complex systems, ecosystems have mechanisms of self-regulation which allow them to maintain system integrity and resilience (Rapport, 1995). Then, the phrase “ecosystem health” has been increasingly used and has continued to evolve rapidly in meaning and application over the last decades (Rapport, 1989, 1993, 1995 and 2009; Spiegel *et al*., 2001; Tzoulas *et al*., 2007); subsequently, the assessment of ecosystem health has been proposed and implemented as a management method (Muñoz-Erickson *et al*., 2007; Lloyd *et al*., 2013). Ecosystem health is an integrative concept used to describe the condition and performance of an ecosystem.

Based on an understanding of the agroecosystem properties and structures (Waltner-Toews, 1996; Okey, 1996), scholars extended the study of agroecosystem health by considering its assessment and implications (Waltner-Toews, 1996; Yiridoe, 1997; Vadrevu *et al*., 2008; Zhu *et al*., 2012). Frameworks and indicators were proposed as ways to evaluate the status of agroecosystems (Smit *et al*., 1998; Altieri and Nicholls, 2003; Xu & Mage, 2001; Su *et al*. 2012). The Agroecosystem Management Program at the Ohio State University (2008) developed a multidisciplinary approach to quantifying agroecosystem health using a combination of soil health, biodiversity, topography, farm economics, land economics, and social organization (Vadrevu *et al*., 2008). GIS software was used to map and examine changes over time in agroecosystem health at landscape scales in this study. According to Gitau *et al*., (2008), agroecosystem health provided a lens for studying the relationship between human health and well-being issues and agroecosystem ecological sustainability for a tropical agroecosystem. One of the foci of their work was to illustrate how community participation methods and soft system methods could be employed in agroecosystem health research. In addition, they integrated the agroecosystem health and sustainability concerns into the practical decision-making considerations. Later, Orozco and Cole (2012) extended this work by taking an ecosystem approach to health in two Ecuadorian provinces with larger indigenous populations and agroecosystems. They studied the multiple drivers of inappropriate use of pesticides with the long-term goal of greater agroecosystem sustainability, including better human health. There is a growing recognition by the scientific community that the research on agroecosystem health which enables systematic assessment of agroecosystems using a multidisciplinary approach can assist in overcoming the challenges of agroecosystem management in a sustainable way (Yiridoe & Weersink, 1997; Liebig *et al*., 2001; Andrews & Carroll, 2001; Gitau *et al*., 2008; Bachev, 2009, 2010; Zhu *et al*., 2012).

Although the study of agroecosystem health have increased markedly in the past few years, limitations are remaining: the methods used in assessments of agroecosystem health are often subjective and themselves controversial; (iii) little work has focused on the relationship between agroecosytem health and management (iv) few studies have addressed how the results of evaluating the health of an agroecosystem can be subsequently used to influence agroecosystem management; and (v) the effects of agroecosystem management on agroecosystem health is rarely documented.

This chapter undertakes a review of the literature pertaining to agroecosystem health, and how this term interplay with agroecosystem management. The purpose of this review is to (i) achieve a better understanding of agroecosystem health; (ii) provide a theoretical basis for developing techniques and approaches that are needed for enhanced agroecosystem assessment.

2.2 Understanding Agroecosystem Health

2.2.1 Agroecosystems

Ecosystems are generally considered to be complex units, comprised of a community (or communities) of living organisms (plants, animals and microbes) in association with the abiotic components and their environment, interacting as a system (Tansley, 1935; Golley, 1996; Okey, 1996; Willis, 1997; Mace *et al*., 2012). Agroecosystems differ from natural ecosystems in several ways. They have the same complex mix of interacting biotic and abiotic factors but are also defined as spatially and functionally coherent units to provide agricultural products and agriculturally related services (Waltner-Toews, 1996; Xu & Mage, 2001). Ecosystems are generally considered to be complex units, comprised of a community (or communities) of living organisms (plants, animals and microbes) in association with the abiotic components and their environment, interacting as a system (Tansley, 1935; Golley, 1996; Okey, 1996; Willis, 1997; Mace *et al*., 2012). Agroecosystems differ from natural ecosystems in several ways. They have the same complex mix of interacting biotic and abiotic factors but are also defined as spatially and functionally coherent units to provide agricultural products and agriculturally related services (Waltner-Toews, 1996; Xu & Mage, 2001). As the basic study unit of agroecology, an agroecosystem is an ecological and social economic system that is comprised of domestic plants and animals, their biotic and abiotic environment and the people who manage the system for the benefit of the society. Agroecosystems are anthropocentric constructs.

Since agroecosystems are directly related to agricultural activities, the definition and scope of agriculture need to be taken into account. Agriculture is traditionally regarded as the science of cultivating plant and raising animals. Caldwell (1996) however, redefined agriculture as the science, art, politics, and sociology of changing sunlight into healthy, happy people. This new definition clarified the multifunction of agriculture that is dependent on capturing the sunlight to make use of natural resources including soil and water to provide food and a healthy environment. The agroecosystem, therefore, not only refers to the agricultural production but also include everything involved in the process of transforming sunlight, soil and water. Thus, agroecosystem is a convenient people-centered term used to include plant and animal cultivation, including agricultural production, forestry, livestock, and fishery.

Agroecology integrates both biophysical and socio- economic dimensions, defining the boundaries of agroecosystem at multiple scales. Agroecosystems, therefore, are not restricted to specific agricultural regions; they also include those regions and ecosystems that are interacting with or being impacted by, the agricultural activity being carried out. Agroecosystems may be described narrowly as small-scale farming systems, or in a slightly broader context as communities or watersheds, or even more broadly on a regional or even global scale (Conway, 1986; Altieri, 1999; Bohlen & House, 2009). Although with high coverages of forestry, based on the definition and scope of agriculture, both Nova Scotia and Fujian provinces were taken as agroecosystems at a regional scale.

However, the most generally accepted definition of agroecosystems restricts the term to a farm system scale, which has limited its application (Altieri & Merrick, 1987; Cassman *et al*., 2002; Tully *et al*., 2013). This definition treats agroecosystems as production units without considering the other social and economic elements, factors that interact with these production systems, as well as the multi-functions of agroecosystems. Defining agroecosystems in a limited way within a farming system can be misleading because the broader reach and interactions that an anthropocentric system implies are not included or considered.

2.2.2 Agroecosystem Health

Researchers have developed definitions for ecosystem health which range from: (i) a broad perspective which integrates ecological, social and economic components; to (ii) definitions that focus on properties and integrity of the system (Conway, 1985); to (iii) definitions using a set of indicators to determine specific aspects of health of an ecosystem (Rapport, 1989; Xu & Mage, 2001). "Ecosystem health," in reference to human reaction to multiple chemical sensitivity and stress from outside, has been used as a medical model to express the status or condition of an ecosystem (Rapport, 1989). Therefore, ecosystem health can be regarded as a term that links human health and well-being to the status of the environment. Some scholars define ecosystem health as the capacity of ecosystems to provide ecosystem services; however, this definition does not address well the critical interface of services and health. A healthy ecosystem should be "stable and sustainable," "which means to be productive, maintain its organization and structure over time and remain resilient to stress (Rapport *et al*., 1998). The common properties proposed by scholars to define ecosystem health are the prevalence of distress syndrome, the capacity to resist disturbance and recover after it (resilience), as well as ecological diversity and stability (Rapport, 1995). However, a healthy ecosystem are also necessary to meet societal needs (Steedman and Regier, 1987; Rapport, 1995).

Some scholars argue that there is no logic for applying the concept of health at the ecosystem level. Calow (1993) noted that ecosystems do not reproduce as unique components and do not have unitary genetic memories. Therefore, ecosystems are not subject to this form of selection and cannot be "programmed" to actively support optimum conditions. However, it can be argued that sustainable ecosystems by definition carry on and reproduce (maintain) themselves and they have genetic diversity as a community that always follows the rules of nature. The structure and function of ecosystems follow a certain pattern even as they are changing temporally and spatially; this is especially true with regard to population dynamics and the cycling of organic matter and nutrients. For instance, healthy ecosystems can conserve water and soil resources, carbon, and nitrogen, purify water and air, and reduce pests, diseases and disasters (Schwinning *et al*., 2004). Rapport (1995) argued that although there are no individual components which are reproduced in an ecosystem based on unitary genetic memories, the ecosystem can still be maintained and well conserved, in order to realize its ideal situation.

Agroecosystem health, as both a theoretical and practical concept, draws on an understanding of historical development and desired futures about overall agricultural ecosystems. Extending the notion of health from a small local scale to a regional scale provides new opportunities to integrate the aspects of social, natural and health sciences. Okey (1996) proposed that a characteristic of a healthy agroecosystem is the balance of stability (multiple states) and resilience, the diversity/complexity maintained, the intrinsic value of wildlife, the aesthetic value of landscapes, equitability in distribution of goods and services among rural population, and the balance of economic and ecological efficiency. Conway (1985) noted that the most significant system properties of agroecosystems are productivity, stability, sustainability and equity. In addition, a healthy agroecosystem not only supplies agricultural production directly and efficiently, but also has greater environmental and social benefits outside of the actual farming system (Porter *et al*., 2009). Waltner-Toews (1996) recognized stability, resilience, diversity, energy use, economic return and moral satisfaction as the basis for agroecosystem health. Xu & Mage (2001) defined agroecosystem health as the system’s ability to maintain its structure, which is required both by its functions and by society over a long time and to produce functions that are desired by society. A healthy agroecosystem is believed to keep itself free from the side effects of disorder syndrome, while maintaining vitality and diversity, coordinating its stability of the organizational structure and achieving high productivity.

Under external stress, its efficient use of resources can maintain continuous production and service capacity for the entire ecosystem. Agroecosystem health is, in fact, dynamic and as a result is associated with dynamic properties such as vigor, organization structure, resilience (maintenance), and equity (noting its special characteristics as human-participated ecosystems) (Conway, 1986; 1987; Rapport, 1998).

2.2.3 Agroecosystem Health Components and Indicators

Agroecosystems are strongly influenced and controlled by human activities conducted for producing agricultural goods, including food and fiber. The status of agroecosystems, in turn, has a cumulative influence on agro-product quality, food security, environmental and human wellbeing. Agroecosystems are characterized as having both ecological and socio-economic components, which affect their overall performance and productivity (Conway, 1987; Marten, 1988; Belcher, 1999). Rao & Rogers (2005) also indicated that an agroecosystem is an ecological and socio-economic system comprised of domesticated plants and animals and the people who interact with them. As a complex system, a healthy agroecosystem is not only a simple aggregation of the list of components, but a unit of interacted parts that change spatially and temporally. The health of the agroecosystem integrates the biophysical, socio-economic components should be taken as the basis for agroecosystem assessment.

2.3 Linking Agroecosystem Health and Agroecosystem Management

Agroecosystem health may be considered the bottom line for any future choices in an agroecosystem (Rapport, 1995). From the perspective of Agroecology, keeping an agroecosystem healthy and viable is the ultimate goal of agroecosystem management. Scientific agroecosystem management should focus on ecosystem sustainability and the relationship between environmental protection and economic development (Zhu *et al*., 2012). Multiple objectives of agroecosystem management are to achieve reasonable and efficient use of agricultural resources, to achieve high agricultural productivity, and to attain balances between ecological, social (including human health) and economic benefits. It is proposed here that the concept and assessment of agroecosystem health have the potential to coordinate all these objectives.

Agroecosystem health, which involves systematic quantitative assessments, is regarded as an essential tool to inform agroecosystem management, by providing new insights into the impact of present practices and new methods of production and management. Agroecosystem health assessment results are valuable for an in-depth understanding of how human activities affect agroecosystem health, as well as how the changes of environment and the driving forces influence these changes. Therefore, the results from agroecosystem evaluation could be used in management strategies from the micro view which may be at the field level (e.g., a farm) versus the macro view which is at the level of society. In this review, agroecosystem health evaluation is regarded as a continuous process; by using the dynamic indices, changes of agroecosystem health in different periods could be monitored. Then, the health status and development trends of the agroecosystem could be determined, and stress factors that threaten agroecosystems could be identified. Agroecosystem health reflects the spatial difference in the distribution of agroecosystem services; it is necessary to adopt proper technical and policy management, adjusted for the differing conditions present spatially. Agroecosystem health assessment is also able to assist in the determination of priorities of ecosystem restoration and policy-making for sustainable land use and agricultural development (Zhu *et al*., 2012).

Well-reasoned agroecosystem management, based on a multidisciplinary approach, is the most efficient way to achieve agroecosystem health. As a typical economic-natural-social composite ecosystem, agroecosystems are human-centered. Therefore, they are always under disturbance and control from a variety of human activities. Human activities that enhance vigor, organization structure, resilience and equality of agroecosystems lead to enhanced health, while human interactions that decrease these properties of agroecosystems cause degradation of agroecosystem health (Costanza, 1995). Also, the health state of an agroecosystem is dependent on technology, policy, economy, culture, and other management factors. Only science-based agroecosystem management, taking all these factors into account, could provide an effective framework for integrated conservation of the ecosystem and enhancement of agricultural production.

2.4 Conceptual Framework for Sustainable Agroecosystem Management

There is no single approach or set of ideas which can address the complexity of agroecosystems and support anticipated outcomes from agroecosystem management. To achieve a healthy and sustainable system at multiple scales from the farm, to the watershed, to the global scale, needs more systematic and holistic approaches to both understanding and managing agroecosystems (Costanza, 1995). A conceptual framework for sustainable agroecosystem management, based on a multidisciplinary approach, is proposed in Figure 2.1.

2.4.1 Farm scale

The optimal status of agroecosystems depends on the level of interactions between the various biotic and abiotic components. Natural resources, including solar, air, water, soil and material, are circulated or recycled by means of energy, material and information flow in an agroecosystem. Therefore, on a farm scale, agroecosystem management can be put into effect by regulating these flows to achieve efficient use of energy and resources in an agroecosystem. This chapter proposes five measures for agroecosystem management on a farm scale: (1) Integrated Plant Nutrient Management, which is customized to a particular crop or farming system, embracing soil, nutrient, water, crop and vegetation management practices. Measurement and regulation of all inputs, including manure, compost, artificial enrichment with CO_2, genetic selection or inhibition of photorespiration and night respiration, can either improve the nutrient balance, as well as forage and crop yields, or minimize the negative impact of the nutrient imbalance; (2) Integrated Soil Management which is defined as a set of soil management techniques aimed at exploiting the optimal use efficiency of soil resources and improving soil physical, biological and chemical properties at the same time. This can be put into effect through (a) minimizing or reducing tillage; (b) planting cover crops; (c) adding organic matter to clay soils; (d) avoiding cultivation or compacting a clay soil when wet; (e) using a raised bed with established walkways, and avoiding walking on the growing bed; (f) increasing nitrogen contributions from legumes; and (g) using manure or cover crops (Lal, 2000; Vanlauwe *et al*., 2010); (3) Integrated Water Management, which focuses on technologies to conserve existing water, to use water resources more efficiently and to avoid unnecessary water fouling. These technologies include drip irrigation, mulching, reduced tillage, windbreaks cover management for shade control and water harvesting, conserve the water and at the same time, have the potential to double, or even quadruple rain-fed crop yields; (4) Integrated Pest Management, which refers to a comprehensive approach to reduce the economic impacts of diverse insects, pathogens, nematodes, weeds, and vertebrates while maintaining a quality environment (Médiène, 2011; Kogan, 1998); (5) Agriculture Landscape and Wildlife Management that aims to increase agricultural productivity, to enhance biodiversity conservation and to improved rural livelihoods (Scherr & McNeely, 2008). Specific measures may include assessing the effects of human activities on wild species by field margin/hedgerows and landscape design, retaining tree cover and adopting biodiversity-friendly cropping systems; precisely applying or reducing fertilizers, as well as combining farming and animal husbandry (Harvey *et al.*, 2008).

2.4.2 Watershed Scale

Effective management of agroecosystems within a watershed scale cannot be achieved unless social-economic factors are taken into account. These management practices require a variety of mechanisms designed to address and meet multiple objectives of agroecosystem management. A variety of organizations from the public and private sectors, plus and groups of stakeholders must be consulted, and the resultant information needs to be reconciled and used to design and apply effective agroecosystem management. Initially, it is necessary for decision-makers to keep themselves well informed regarding changes in agroecosystem status. The policy-making mechanism needs to bring the viewpoints and information from diverse groups such as producers and consumers and the public, into focus. General knowledge of processes and ecosystem status, combined with good social and scientific knowledge will help promote and develop good policy. In addition, within a watershed agroecosystem, participatory multi-stakeholder mechanisms link all levels of organizations and individuals, including consumers, producers (e.g. farmers), researchers, scientists, policy-makers, and the public. These participatory connections promote information sharing among people with different knowledge and experiences. At the same time, education on how to re-examine the relationship between people and nature, as well as research on agroecosystem assessment, are important and necessary. Furthermore, based on good knowledge of agroecosystem structure and process, a mechanism for ecological compensation, can be developed as a tool in watershed management. However, this ecological compensation mechanism requires the assistance of market mechanisms which can provide scientific information on the value of each agroecosystem service (Zhu *et al*., 2012). For example, an ecological compensation mechanism may apply to environmental losses associated with agricultural activities. Unanticipated environmental damage can be measured and be paid for by people who caused or who are going to cause the damage.

2.4.3 Global Scale

Sustainable agroecosystem management must incorporate the socioeconomic, environmental and ecological objectives on a global scale. Firstly, to support these goals, scientists must develop innovative, multi-objective decision-making tools which can guide agroecosystem management. Secondly, the study of Agroecology, which is based on systems thinking and a systems approach, supplies a multidisciplinary and interdisciplinary framework for understanding the relationships among the social, ecological and economic concepts involved (Altieri & Merrick, 1987; Wang & Caldwell, 2013; Wezel *et al*., 2014). Thirdly, the assessment of agroecosystem health has been recognized as one of the most effective ways to acquire a scientific understanding of agroecosystem structure and process (Andrews & Carroll, 2001; Horwitz, 2011; Rapidel *et al*., 2015). The assessment results can also provide information on how the agroecosystems are organized, how they function, how their conditions change and are maintained and how they interact with the social systems of people (Rambo, 1984; Marten, 1988). Finally, international cooperation is vital to tackle environmental problems, including global warming, biodiversity loss, water pollution, and enhance agricultural production on a global scale. This requires a platform for the researchers and scientists to share information. Dialogue among leaders from different countries should be developed and shared interests should be found on a global scale, in order to reach an agreement on how global problems can be solved.

This conceptual framework illustrates how agroecosystems could be managed from farm scale, watershed scale and global scale, based on scientific understanding of agroecosystem health. The goal of this framework is to make food production more efficient, while conserving agroecosystem health. This framework combines different management mechanisms from a macro view, and proposes sustainable agricultural practices from a micro level (Zhu *et al*., 2012).

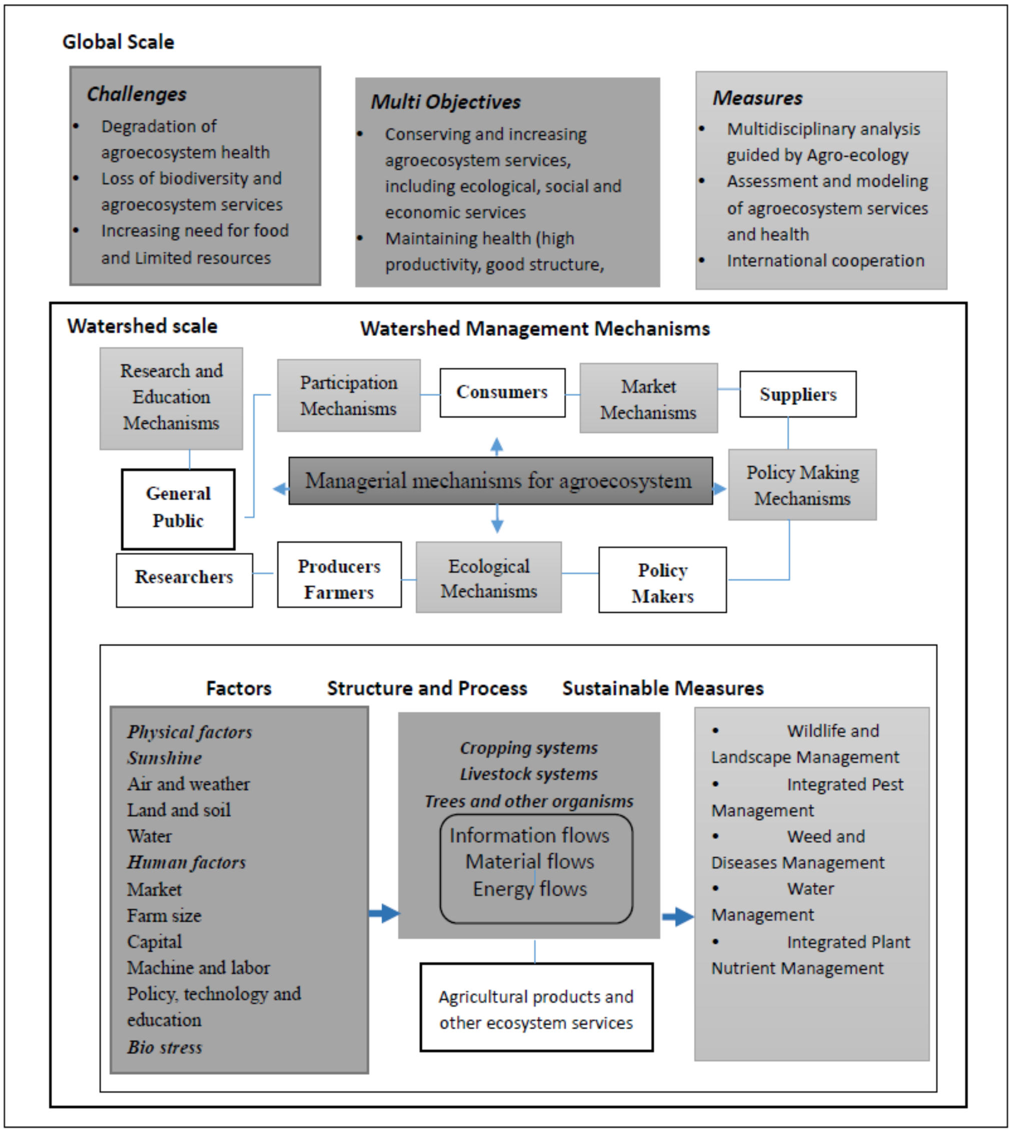

Figure 2.1 Conceptual framework for sustainable agroecosystem management
Note: adapted from Zhu *et al*., 2012

2.5 Conclusion

There is a need for more research available to explore the concepts and application of agroecosystem health to find a resolution to theoretical and methodological issues, which inform policy making (Fishera *et al*., 2009). However, researchers have not come to a consensus on a standard definition of agroecosystem health which is based on the observed characteristics of agroecosystems. In addition, there is a lack of scientific understanding on how agroecosystem health relates to, and influences management goals. This may lead to misunderstandings concerning the relationship between humans and nature and thus further exacerbate the environmental crisis. This review of the literature has outlined the definitions of agroecosystem health and has proposed how it could be linked to help inform agroecosystem management.

Based on a better understanding of the agroecosystem, an ideal conceptual framework for sustainable agroecosystem planning is proposed. The conceptual framework for sustainable agroecosystem management, based on multiple disciplines, is formulated from a systematic review. Agroecology serves as a basis for integrating multi-disciplines on a global scale. The assessment of agroecosystems assists agroecosystem management by informing land managers in facilitating decisions about complex issues. Platforms for dialogues among scientists, researchers and policymakers are required. Then, on a watershed scale, coordinated mechanisms can promote a better understanding of the agroecosystem structure and guide agroecosystem management in a social and policy perspectives. These mechanisms are decision-making, participatory, ecological, market, as well as research and education mechanisms, and involve a variety of organizations from the public and private sectors and groups of stakeholders. Moreover, on a farm scale, technical practices including Integrated Plant Nutrient Management, Integrated Soil Management, Integrated Water Management and Integrated Pest Management are presented in this review. These management systems and practices aim to realize the multiple objectives of agroecosystems by directing and regulating the energy and information flows. Of importance is the fact that the relationship between agroecosystem services and health should be considered when designing new management practices and complex crop rotations.

We recommend that future research in this area take the spatial-temporal dynamic changes of agroecosystem services and health into account. A future direction of inquiry should employ case studies to monitor how agroecosystem health and services change and interact with each other; such an undertaking would provide specific data for analysis and interpretation for agroecosystem assessment. In addition, comparative research could be conducted on a global scale, in order to establish relatively unified methods, frameworks, data analyses and should include tools which help with data analyses.

There is little doubt that defining agroecosystem health and analyzing how it relates to agroecosystem management, will provide a theoretical basis for developing techniques and approaches that are needed for enhanced agroecosystem assessment and management. At the same time, such research in the recent past has become a useful tool but only the start for further more theoretical and empirical research into agroecosystem management.

CHAPTER 3 A SINO-CANADIAN COMPARATIVE STUDY OF EXPERTS' PERCEPTIONS TOWARDS AGROECOSYSTEM HEALTH

3.1 Introduction

An agroecosystem, as a spatially and functionally coherent unit related to agricultural activity, includes the living and nonliving components involved in that unit, as well as their environment and interactions (Conway, 1984; Smit, 1998). An agroecosystem is strongly influenced and controlled by human activities for producing agricultural goods, including food, fiber and other economic resources. The status of agroecosystems has an increasingly substantial effect on agro-product quality, food security, biological security and human health. Over the past century, agroecosystems have been degraded significantly through unsustainable methods largely dependent on fossil fuel input (Horrigan *et al*., 2002). Therefore, maintaining and increasing agricultural production, while optimizing the status of agroecosystems, is one of the major challenges for farmers, researchers and policymakers.

There is growing interest in the theory and methods for assessment of agricultural systems because of the realization that these approaches have the potential to inform agricultural management strategies. Despite this growing interest and activity, there continues to be a lack of scientific basis for a large-scale assessment of agricultural ecosystems that integrates ecological, social and economic aspects of agroecosystem viability. A critical challenge in agricultural system assessment is the need to consider multiple disciplines and perspectives in standardized evaluations whether on a global, provincial or watershed scale.

Rather than consider one issue or factor in isolation, it is necessary to develop a systematic understanding of the biological-social-economic condition. Agroecology has been defined as the science of applying ecological concepts and principles to the design and management of sustainable food systems. It is an integrating discipline that includes elements from agronomy, ecology, sociology and economics; agroecology develops systematic thinking that focuses on an understanding of agricultural systems by exploring the linkages and interactions between distinct parts of an agroecosystem. The multidisciplinary approach of agroecology can provide the reasoned basis for agricultural ecosystem assessment and management.

Agroecosystem health, as an agroecological concept for analyzing and managing agroecosystems, has gained prominence in recent decades (Yiridoe & Weersink, 1997; Xu & Mage, 2001; Altieri & Nicholls, 2003; Vadrevu *et al*., 2008; Zhu *et al*., 2012). Research on agroecosystem health has been stimulated by a desire to assess conditions, to understand the processes and structures in greater depth, and to identify how to improve overall status (Waltner-Toews, 1994). Interest in agroecosystem assessment and analysis is growing; however, few studies have been conducted using an integrated, systematic framework for evaluating agroecosystem health. There is a lack of research or dialogue among economists, ecologists and sociologists on a global scale. Some studies have attempted to apply a framework to evaluate agroecosystem health (Smit, 1998; Altieri & Nicholls, 2003; Xu and Mage, 2001; Su *et al*., 2012), but lacked a clear identification of how the agroecosystem health criteria are selected and used (Yiridoe & Weersink, 1997). In addition, difficulty in establishing a uniform systematic and scientific evaluation index system has become the bottleneck of agroecosystem health research (Zhu, 2012). Moreover, very few studies have addressed national and cultural differences in perceptions and knowledge of agroecosystem health that would explore global differences.

Societal values, perceptions and attitudes towards agroecosystem health directly affect environmental education and policymaking, which are vital to the environmental protection and agroecosystem management (Tuan, 1990; Kollmuss & Agyeman, 2002; Dietz & Shwom, 2005; Markle, 2013, Kohler, 2014). Experts' opinions and knowledge can inform and influence the public's values, behaviors and attitudes. In order to address the multiple goals of agriculture, the voices of diverse experts in ecosystem evaluation are essential (Crome, *et al*., 1996; Curtis, 2004; Mac Nally 2007; Xie, *et al*., 2008; Kuhnert, *et al*., 2010; James, *et al*., 2010). Therefore, an investigation of experts' opinions would provide a means to approach agroecosystem health in an interdisciplinary, systems-based approach. This serves as the basis for negotiation and consensus building in identifying crucial components of an index, as well as a guide to evaluation and management of agroecosystems (Gitau *et al*., 2008).

Deng *et al*. (2006) commented that the traditional values, attitudes, and perspectives of a given society greatly affect the response to environmental problems. Ecological and environmental problems are particularly noticeable in China, a developing country with a large population. Canada has more natural resources on a per capita basis than China but still faces environmental challenges that could indirectly translate to differences in agroecosystem health. The different situations in Canada and China present different unique environmental challenges. Hence, it is necessary to understand how, or if, whether the population's values, perceptions and attitudes toward ecosystem and environmental values lead to the different agroecosystem assessment frameworks and ultimately ecosystem outcomes.

This study establishes an integrated framework for agroecosystem health, from perspectives of Ecology, Sociology and Economics, based on a survey conducted in both Canada and China. The focus of this research is to initiate a dialogue among ecologists, economists and sociologists, on a global scale. I aim to answer the following questions: (i) Are there differences in the identification and ranking of assessment indicators for agroecosystem health between and among experts from different countries (China and Canada) and different disciplines (Life Sciences/Ecology, Sociology and Economics)? (ii) What are some of the factors that may cause these differences? This paper explores attitudes toward agricultural ecosystem evaluation frameworks in cross-discipline and cross-cultural comparisons.

3.2 Data and Methods

3.2.1 Study Design

This study collected and analyzed opinions from experts (ecologists, sociologists and economists) in order to examine whether there are differences in perceptions of agroecosystem health between Canadian and Chinese experts from diverse disciplines. The Delphi technique, which is a widely used method for achieving convergence of opinion concerning real-world knowledge, was employed in this research (Linstone & Turoff, 1975; Hsu & Sandford, 2007). Data on the perceptions of agroecosystem health were explored in general; area of ecology, economic and social aspects. In the first round of survey, the discipline experts (Life Sciences/ Ecology, Sociology and Economics) were asked their opinions regarding the indicators that are important to agroecosystem health. After analysis and collation of those results; experts were asked to rank the relative importance of previously identified indicators in the second survey round. Then, by measuring group means of the rankings, as well as employing Chi-Square tests, differences in the preferences towards agroecosystem health indicators between experts from different countries and within a county from different disciplines were evaluated.

3.2.2 Selection of Participants

The theoretical population for this study is defined as all experts, including professors, researchers or recognized instructors at an agricultural college or universities in Canada and China, and who were experts in the three general areas by virtue of the employment. In order to investigate the effects of nationality and discipline on perceptions of agroecosystem health, scientists who have expertise in these three disciplines, from Canada and China, were selected to participate in the surveys. Selection began from a wide list drawn from attendees pertaining to conferences, and authors in journals and books on related topics as well as researchers listed on the websites of universities and research institutions in these fields.

3.2.3 Surveys and Questionnaires

Dalhousie University's web survey software Opinio (Object Planet, 1998-2014) was used to carry out the surveys. Online survey panels were created and respondents were invited via email to participate in the survey (Appendix A). Individuals received the surveys with an information cover letter that outlined voluntary participation of the survey, contact information of the researchers and, background and aim of the survey, how the results of the research could be acquired, what methods would be undertaken and what participation was being requested. Ethics approval for this research was granted by the Research Ethics Board of Dalhousie University before the surveys were carried out.

Surveys were conducted between 9 October 2013 and 18 August 2014. There were two rounds of surveys (first identifying the indicators and second ranking the already stated indicators according to their perceived importance) for this study. The questionnaires (Appendix A) in each survey round included three main sections: ecological aspect, social aspect, and economic aspects and were available in both English and Chinese. All respondents were asked to provide their experts opinions on indicators in all categories, irrespective of their specific professional expertise. In the first phase of the investigation, the experts were asked to identify indicators that are significant to agroecosystem health. The surveys asked that the experts provide all the indicators they considered to be important to agroecosystem health. In the second round, they were asked to rank the importance of the list of indicators compiled from their own country colleges that were suggested by the experts from their own country in the first round of the survey.

3.2.4 Data Collection and Analysis

In the data from the first survey round, the indicators suggested by the experts were qualitative variables (name of the indicators), while the data from the second round were ordinal scales reflecting the ranking of each indicator. Datasets for statistical analysis were the rankings of jointly identified indicators by both Canadian and Chinese experts, which were extracted from the second survey round. It consisted of 120 observations on 13 indicators from both Canadian and Chinese participants.

The indicators identified in the first round of survey were compared and analyzed qualitatively. Then, descriptive statistical analyses were conducted on the ranking of indicators (survey 2) by using IBM SPSS 22.0 based on the second survey round. By measuring means of the indicator rankings among subgroups (Life Scientists/Ecologists, Sociologists, and Economists groups between Canada and China), the relative priorities of the indicators and how these priorities varied among different subgroups were observed. Finally, Chi-square analyses were conducted to determine whether experts' preference of indicators significantly differed among different nationality and specialty groups. Significant interactions at the $p < 0.05$ level were identified in the Chi-square analyses.

3.3 Results

3.3.1 Response Rates

In the first round of the survey, the number of completed questionnaires was 72 of 350 experts (20.6%) from Canada and 94 of 450 (20.9%) from China. Of the Canadian respondents, 37% were in Life Sciences, 39% in Social Sciences and 24% in the areas of Economics. Among the Chinese experts participating, the majority (60%) were in Life Sciences, while the remaining 40% were split equally between Social Sciences and

Economics (20% each). In the second round of the survey, for Chinese experts the number of completed questionnaires was 56 of 331 (16.9%) (Life Sciences: 59%, Social Sciences: 21%, and Economic Sciences: 20%) and for Canadian experts 64 of 442 surveys were completed (14.5%) (Life Sciences: 37%, Social Sciences: 29%, and Economic Sciences: 34%). Worthy note in the relatively larger participation of Chinese experts in the field of life science for the second survey.

3.3.2 Identification of Agroecosystem Health Indicators

The results of the first round of the survey showed that there were significant differences in the indicator generated by Canadian experts and Chinese experts. There were 28 indicators were identified by Canadian experts (9 ecological indicators, 9 social indicators and 10 economic indicators) and 32 indicators were identified by Chinese experts (10 ecological indicators, 11 social indicators and 11 economic indicators) (see Table 3.1).

Among those suggested indicators, fewer than half of the indicators (12 out of 28 or 46%) were common to the lists generated by both Canadian and Chinese experts. The common indicators are *soil organic matter, soil erosion and contamination, air quality, water quality, biodiversity, land cover diversity or coverage, extension and availability of social services, happiness of the population, Gini index (fairness and equality), GDP per capita, farm stability and resilience, energy, and resource efficiency*. Most of the ecological indicators identified were concerned with natural resources; The social and economic indicators suggested by Canadian and Chinese experts were similar, but some had different expressions that were country-specific. For instance, the extension and availability of services stated by Canadian experts was expressed as social services by Chinese experts. In addition, Canadian experts placed energy efficiency within ecological indicators, but Chinese experts included this term within the economic category.

Overall, the between-country evaluation indicated that the identification agroecosystem health indicators had more in common with respect to ecological aspects, that was the case for the social and economic dimensions. It also demonstrated tremendous differences among specialists with respect to social indicators and economic indicators, but showed more commonality to the ecological indicators names across all disciplines.

3.3.3 Rankings of Agroecosystem Health Indicators

The indicators were sorted by their group means for each group from the lowest to the highest. The scores were ordinal with the most important being ranked as one. A lower mean score indicates a greater perceived importance by the experts; this was used to assign the rank (i.e. priority). According to the responses from Chinese experts, *soil organic matter content* was the most important ecological indicator, followed, in order of priority, *by soil contamination and agricultural productivity* (Table 3.1). The most important social indicator for agroecosystem health was identified as *food safety*, followed by *human health*. Regarding the economic indicators, the top three by Chinese respondents were *energy and resource efficiency, the intensity of using pesticides*, as well as *agricultural plastic films and fertilizer*.

When it came to the Canadian experts, *soil erosion and contamination* along with *soil organic matter content* were also given the highest ranks among the ecological indicators. The most important social indicator was *rural community sustainability (including human health)*, followed by *percent population above the poverty line* and *fair return for farm labor*. The Canadian experts ranked *family income stability* as the most important economic indicator followed by *farm income stability and resilience*, and *farm debt*.

Overall, the survey found that soil indicators (*soil organic matter*, *soil contamination and soil erosion*) were the most important ecological indicators according to both Canadian and Chinese experts, although they differed on social and economic indicators. Canadian experts on average paid relatively more attention to *the sustainability of community and farm*, while Chinese experts gave a relatively higher priority to *food safety and human health*, as well as *the efficiency of energy and resources*.

The differences among the three specialty groups and nationality groups were compared for the 13 common independent variables in both China and Canada by Chi-square tests (Table 3.2). The Chi-square test results indicated that there were country differences in the ranking of most of the commonly identified social and economic indicators ($P < 0.05$), but no significant differences among specialty groups. The indicators which showed significant differences between nationality groups include three of seven ecological indicators (*air quality, biodiversity and land cover*), two of three social indicators (*social services, human happiness*), and two of three economic indicators (*Gini coefficient, farm stability & resilience and energy efficiency*) as showed in Table 3.2. In contrast, only land cover and energy efficiency showed significant differences between specialty groups.

3.4 Discussion

The findings of this study suggest that, overall the opinions of Canadian experts on key criteria to gauge agroecosystem health were very different from Chinese experts. Fewer than half of the selected indicators were common to both countries and, especially for social and economic indicators, the priorities of the indicators were significantly different between the two nationality groups. There were significant differences with regard to the selection of the indicators between experts from different specialization areas once asked to rank a list of indicators of indicators provided were not significant difference between specialists. In general, the results provided evidence of the global environmental attitudes associated with and influenced by societal and cultural context.

3.4.1 Difference and Similarity between Canadian and Chinese Experts

The results demonstrated similarities for the ecological indicators, especially on *soil erosion, soil contamination, soil organic matter* and *water quality*. This result is similar to a previous study by Deng *et al*. (2006) which determined that Anglo-Canadians and Chinese in Canada were not significantly different in their biosphere values. A plausible reason for the observed similarities could be that human beings have started to realize on the importance of harmony between humans and nature on a global scale. The traditional Chinese view of a harmonious relationship between humans and nature has been diminished from earlier times. This may be the result of the long-term goal of economic development, based on Chinese national conditions or increased contact with Western practices. In order to enhance the living standards of a large population, the willingness to change nature has grown. Consequently, the harmony between humans and nature may have been greatly impacted in a country like China. Canada, as a developed country, learned from the Industrial Revolution and the ‘dust bowl’ of the 1930’s that much of the environment is destroyed by over-exploitation. As a result, many Canadians (including the experts in the panel) have partially changed the past view that humans are masters over nature (Deng *et al*., 2006). In addition, the natural resources, including soil, water, air, and biodiversity, are the basis for human survival and development all over the world. Therefore, Chinese and Canadians have a convergence point on the importance of ecological sustainability and the fundamental importance of protecting soil and water resources. Also, these choices of ecological indicators could reflect that the natural resources, including soil, water, air, and biodiversity, are the basis for human survival and development all over the world. Compared with social and economic indicators, ecological indicators, even in diverse cultural contexts, appeared to follow a similar general pattern and raking of importance.

Diverse backgrounds societal cultural and environments in the two countries cause people to think and act differently (Leung & Rice, 2002; Cordano *et al*., 2010). In China, as the population increases, social and economic problems, including the competition among limited land resource and the increasing population and local food insecurity, as well as the lack of energy and natural resources, are the major factors hindering the sustainable development of agriculture and agroecosystem maintenance. Therefore, *food safety and human health*, as well as *energy availability and efficiency* have been the primary focus for the Chinese people (Li *et al*., 2013; Ni & Zeng, 2009). In Canadian agroecosystems, a variety of social and economic factors, including high personal and public debt loads, disappointing income levels and income disparities within the country, as well as unemployment threaten agroecosystem services, long-term sustainability and health (Pomfret, 2013; Walks, 2013).

One of the most important findings of the study showed that soil factors, such as *organic matter, soil erosion and soil quality* were consistently a priority in both countries. This is supported by the literature, which addresses the importance of soil and how soil supports and influences agriculture and ecosystems. The soil is closely related to all aspects concerning human beings and plays an important role in sustaining life on Earth. It is not only the most significant resource upon which agriculture is based, but also is the basis of biodiversity, water, gas exchange, energy and habitat for human beings. However, research has suggested that, with the extensive development of agriculture and irrigation of land-use, soil resources are increasingly degraded and eroded on a global scale (Kassam *et al*., 2014). Soil quality, in agree with Herrick (2000), could be regarded as a perfect indicator of sustainable land management. These facts illustrate the reasons why soil indicators were the most important ecological indicators identified both between discipline experts and between nationalities in the present surveys.

3.4.2 Difference and Similarity among Academic Discipline Groups

The results showed that the indicators that were provided by experts from different disciplines varied greatly. The differences between specialties could be explained by knowledge and discipline experience and innate sense of the importance of their professional discipline. From the natural ecological concept, experts from life science focus on the balance between the utilization and protection of natural resources, as well as the stability and resilience of the ecosystem. Sociologists regard humans as the center of development; stable and equal social and political environment and the improvement of living quality are crucial to human survival and development; while economists consider that accumulation of capital and growth of benefits are necessary steps to promote a higher standard of living and economic health in a specific area (Sen, 1983). Therefore, the experts provided those indicators they thought were important, based on their knowledge, experiences and the values of their discipline group. In fact, this was also a process for promoting dialogue among experts from the three disciplines (Dobbin & Baum, 2014).

Furthermore, *energy efficiency* was included as an ecological indicator in the Canadian list of indicators, but as an economic indicator in Chinese agroecosystems. This implies that Canadian experts regarded energy efficiency as a natural part of the ecosystem, but Chinese experts were more focused on the economic aspects of energy production and resource allocation. Energy usage in agriculture competes greatly with other industries in China where energy is in relatively short supply compared to Canada. In China, energy is widely viewed as a critical means to develop the economy; it appears in some of the present economic policy in China, and that may influence people’s opinion. In Canada, energy efficiency may be considered as a means to decrease the ecological and climate change impact of energy used in agriculture, resource and other industry sectors. This reflects the fact that Canada is a country with abundant energy resources, while China possesses a plentiful labor force and a huge market, but relatively limited resources and energy for the size of its population (NBS, 2014).

Although these explanations for the results are based on the fundamental national conditions of the two countries, all the explanations need to be further tested. The differences due to the nationalities and specialties of the experts are obvious in the data. However, a previous study also suggested that the experts' genders, ages, and social status might influence how they responded to the survey (Burn *et al*., 2012; Zhou, 2013). In addition, there was one issue concerning the interpretation of results between the two countries. Although the questionnaires were translated into both languages, it is not certain that all vocabularies and sentences expressed exactly the same meaning. This is particularly problematic because there might be a misinterpretation by certain experts because technical comprehension might differ between cultures and languages.

3.4.3 Limitations and Application

The sample size, as well as the balance of a number of experts among disciplines of this research, may also have affected the comparative results. The balance of the number of Chinese experts among disciplines was a little more skewed (i.e., proportionately more life sciences than other disciplines) in both surveys, compared to the Canadian mix of experts. Although this might affect the analysis of the differences in perceptions of agroecosystem health among experts from different disciplines, the results for the differences in attitudes towards agroecosystem health between Canadian and Chinese experts are not affected. It is encouraging that in the first round, the mix and number of indicators suggested were approximately even across ecological, social and economic indicators for both countries. This suggests that, regardless of a disproportionate number of experts among different disciplines, balanced frameworks in both countries were achieved.

In addition, societal values, perceptions and attitudes have played essential role in the difference in the agroecosystem health indicators for the cross-national comparison as presented in the study. Given that agricultural ecosystem in the two nations is very dissimilar regarding commodities produced, the technology utilized, natural resources, both in terms of quantity and quality; these distinctions joined with different land use practices, would also play a role. The range of agricultural practices across both countries is quite important which would likely affect the importance of an indicator, which may depend on which part of the country the participants come from. A comparison of agroecosystem health indicators for regions where similar agricultural or land use practices and environmental challenges take place, for example, dryland farming land would likely be useful.

We recommend that future research in this area take experts' genders, ages, social status and other factors into account. Future studies should be focused on current environmental attitudes and values of the populations and how these attitudes change as the cultures vary. In addition, the scale of research could be extended to more countries and the public, especially farmers, could be included as survey respondents.

This research examined the similarities and differences in perceptions of key criteria to assess agroecosystem health between Chinese and Canadian experts. It provides not only bases for agroecosystem evaluation and management systems, but also an opportunity for sharing ideas and for dialogue among ecologists, sociologists and economists, on a global scale. It is valuable to international research on agroecosystem health and the relationship between cultural factors and environmental attitudes.

This study has defined criteria (indicators) for agroecosystem health evaluation in both Canada and China. The chapter has identified three key indicators that were jointly suggested by Chinese and Canadian experts. Based on the ranking of those jointly identified indicators, soil erosion, GDP, and human happiness and health, have been suggested as primary indicators, from the perspectives of ecology, economics and sociology respectively. It would be ideal to use multiple indicators from each discipline, but the following chapters will use only one indicator for each discipline as a starting in building a good model for evaluating ecosystem health. Thus, spatial and temporal changes of soil erosion, GDP, as well as human happiness and health in Nova Scotia and Fujian, will be analyzed and discussed in next three chapters.

Table 3.1 Rankings of selected indicators to assess agroecosystem health by Chinese and Canadian experts

Chinese Experts			**Canadian Experts**		
Indicators	**Rank Mean**	**Rank**	**Indicators**	**Rank Mean**	**Rank**
Ecological indicators			**Ecological indicators**		
Soil organic matter	3.96	1	Soil erosion and contamination	3.59	1
Soil contamination	4.15	2	Soil organic matter	3.76	2
Agricultural productivity	5.07	3	Diversity of plant, micro and macrofauna	4.00	3
Soil erosion	5.41	4	Biodiversity of land cover	4.64	4
Water quality	5.46	5	Water quality	5.23	5
Biodiversity	6.89	6	Biodiversity of natural habitat	5.59	6
Natural resources and ability	6.93	7	Air quality	5.79	7
Vegetation coverage	7.44	8	Energy availability	6.57	8
Air quality	7.57	9	Energy efficiency	6.87	9
Protection measures	8.45	10			
Social indicators			**Social indicators**		
Food safety	3.00	1	Rural community sustainability (including health of people)	3.11	1
Human health	3.93	2	Population above poverty line	4.27	2
Ecological compensation mechanism	5.23	3	Fair return labor	4.45	3
Education and training	5.61	4	Existence and activity of community and organizations	4.85	4

Chinese Experts			**Canadian Experts**		
Indicators	**Rank Mean**	**Rank**	**Indicators**	**Rank Mean**	**Rank**
Population structure	5.70	5	Happiness of people	5.30	5
Public infrastructure and service	5.75	6	Gini index	5.31	6
Happiness index	6.78	7	Extension services availability	6.27	7
Fairness and equality	7.07	8	Social diversity	6.48	8
Engel coefficient	7.67	9	Percentage of rented land	6.52	9
Rural urbanization	7.80	10			
Economic Indicators			**Economic Indicators**		
Energy and resource efficiency	4.00	1	Family income stability	3.66	1
Intensity of using pesticide and fertilizer	4.71	2	Farm stability and resilience	4.13	2
Resource self-supporting	5.48	3	Farm debt	5.07	3
Agricultural infrastructure	5.79	4	Farm profitability	5.07	4
Production efficiency	5.88	5	Farm land values	5.68	5
Food self-supporting	6.09	6	GDP per capita	5.69	6
Diversity or number of crop varieties	6.14	7	Products prices	5.82	7
Industrial structure and business model	6.61	8	Value of food chains	5.98	8
Income or GDP per head	7.05	9	Health costs per capita	6.77	9
Gap between the rich and the poor	8.45	10	Education costs per capita	6.92	10

Note: All indicators were ranked from 1 to 10 with 1 being the highest priority indicator within each indicator category.

Table 3.2 Chi-Square analysis of nationality and specialty groups of rankings of indicators selected by both Chinese and Canadian experts

	Nationality		**Specialty**	
	df	**P value**	**df**	**P value**
Soil erosion	12	0.201	24	0.587
Soil contamination	9	0.514	18	0.23
Soil organic matter	11	0.247	22	0.459
Air quality	12	0.04*	24	0.578
Water quality	11	0.126	22	0.205
Biodiversity	13	0.014*	26	0.051
Land cover	12	0.004*	24	0.019*
Social services	11	0.038*	22	0.395
Human happiness	11	0.001*	22	0.853
Gini coefficient	11	0.012*	22	0.353
GDP per capita	10	0.167	20	0.93
Farm stability and resilience	11	0.049*	22	0.056
Energy efficiency	10	<0.001*	20	0.04*

Note: The P values with "*" indicate that the main effect of the factor has a significant effect on the response.

CHAPTER 4 MEASURING THE HEALTH COMPONENTS OF AGROECOSYSTEMS IN SPACE: AN EMPIRICAL EXPLORATION USING GIS

4.1 Introduction

Agriculture has made significant contributions to the advances in economic development and human society. Coupled with this achievement, however, are the degradation of the natural environment and loss of other services provide by the ecosystem, such as clean water and productive soil (Nair, 2008). The challenge for the agricultural producers, research community and decision makers is to sustain the economic capability of agricultural production and improve the quality of life, while protecting the environment and services provided by the ecosystems (Olsson and Ardö, 2002; Bakr *et al*., 2012; Foley *et al*., 2011; El-Sharkawy, 2014; Crosson and Anderson, 2014). This reinforces the need for a transdisciplinary approach to understand this challenge and develop ecological and socio-economic insights to gauge and inform the current issues and explore options for sustainable development (López-Ridaura, Masera & Astier, 2002).

Agroecology has emerged as an approach that emphasizes the principle of system thinking to solve actual challenges of the agricultural system encompassing biophysical, economic and social dimensions (Swanton & Murphy, 1996; Hodbod & Jennifer, 2016). Rather than identifying a list of problems and solving them individually, agroecologists consider that the various issues come from an entire package functioning as interactions of various components (Glaser, 2006; Herrmann, van de Fliert & Alkan-Olsson, 2011; Hoy, 2015). Agroecosystems, the basic units of agroecology, are strongly influenced and controlled by human activities used to produce agricultural goods, including food and fiber. The status of agroecosystems, in turn, has major influence on agro-product quality, food security, the environment and human well-being. Agroecosystems are complex functional units which are made up of diverse components (Belcher, 1999). The system is unsustainable if any of the components are malfunctional because of the interdependence of these components. The complexity of the agroecosystem leads to the need for integrative assessment methods that can improve understanding of agroecosystems and establish long-term sustainability of agroecosystems with consideration of the various components (Gliessman, 1990; Ananda and Herath, 2003).

A model of agroecosystem health could serve as one such integrative approach that incorporates a range of disciplines from the biophysical, social and economic sciences designed to assess the status and performance of an agroecosystem holistically. There are increasing efforts being made to explore different approaches to agroecosystem health evaluation. One of the approaches is to utilize frameworks with various indicators to evaluate the status of various components of agroecosystem (Yiridoe & Weersink, 1997; Xu & Mage, 2001; Vadrevu *et al*.,2008; Hoy, 2015; Peterson *et al*., 2017); endeavors of such theoretical research are applied to practical situations at different scales (e.g., field, farm, landscape, regions, nations). Most of the definitions of agroecosystem health emphasize both biophysical and social-economic dimensions (Vadrevu *et al*.,2008; Hoy, 2015; Peterson *et al*., 2017); however, some studies focus on the biophysical components of the system, while others are more concerned with the social and economic performance of the system (Xu & Merge, 2001). In the literature, there is a lack of empirical evaluation of agroecosystem health focusing on all three dimensions, at a regional scale in a global context. Also, very few studies have taken a practical approach to address agroecosystem vitality in space across scales because of the limited availability of data required in such research.

This chapter presents an empirical study of agroecosystem health from the perspectives of ecology, economics and sociology on a provincial scale within a global context. This study demonstrates the application of GIS as a tool to combine remote sensing data and census data in agroecosystem assessment, using Nova Scotia and Fujian provinces as case studies. This study answers the following three questions: (i) how can GIS be utilized for successful monitoring of ecological, social and economic components of agroecosystem health on a large scale in a global context; and (ii) how do these three key indicators of agroecosystem health, including soil erosion, GDP and human health and happiness, change spatially across scales (provincial and sub-resions) in the two regions.

4.2 Overview of Selected Agroecosystem Health Indicators

In Chapter 3, criteria, also referred to as indicators, of agroecosystem health evaluation were identified by both Canadian and Chinese experts. Those proposed indicators were ranked by their relative importance to the overall health of an agroecosystem, by ecologist, economists and social scientists. Based on the rankings of jointly identified indicators from the Chapter 3, soil erosion, GDP, and human happiness/health, were identified as key indicators, from ecological, economic and social aspects, respectively. While it would be ideal to use multiple indicators from each discipline, here only one common indicator for each discipline was used as a starting point in building a model for evaluating ecosystem health.

4.2.1 Selected Ecological Indicator - Soil Erosion

Ecological /biophysical indicators could provide information on the status of ecosystems and the impact of human activity on ecosystems. One of the most important components of the biophysical environment is the soil resource. Soil erosion, as a major type of degradation of soil, refers to the displacement of soil from the Earth's surface by exogenetic agents (e.g., water, wind, gravity) and its deposition at a digressional or protected site (Blanco *et al*., 2010; Toy *et al*. 2002). Soil erosion is a naturally occurring biophysical process, but it has been accelerated by the human activities, especially agricultural activities. Excessive erosion not only interferes with agricultural production but also causes serious environmental problems, such as desertification; and ecological collapse due to the loss of organic matter and nutrient-rich upper soil layers; and sedimentation and pollution of waterways due to large amounts of transported sediment and nutrients; (Blanco *et al*., 2010; Toy *et al*., 2002). In addition, soil erosion can reduce the ability of soil to mitigate the greenhouse effect due to disturbance of the balance of carbon in soil (Yang *et al*., 2003). To respond to serious erosion concerns and to mitigate and reduce their negative effects, better information is needed on the erosion sources, as well as the spatial patterns of soil erosion. Studies on soil erosion assessment are essential for land use planning and conservation.

4.2.2 Selected Economic Indicator - GDP

Several indicators are commonly used to measure the performance of economic development. The gross domestic product (GDP) has been widely used as a leading measure of economic performance in different regions, especially for cross-country comparisons (Lequiller & Blades, 2006). It accounts for the monetary value of all the finished goods and services that are produced within a country's economic territory during a given period. Moreover, some of the economic measures, including GDP, have been employed as the key indicator for environmental assessment and agroecosystem evaluation (Moffatt, 1994; Gallopin, 1996; Winograd & Farrow, 2009).

4.2.3 Selected Social Indicator - Self-Perceived Human Health and Happiness

Social indicators examine how well a population or society's needs are being satisfied. Human happiness refers to the degree to which the individual judges the overall quality of his/her own overall life. “Subjective well-being” and “life satisfaction” are alternative terms used in happiness research. As Helliwell *et al*. (2012) indicated it would not be possible to understand human happiness without knowing what human beings say. Self-assessed measures of social indicators provide a subjective but important evaluation of overall status. Although self-assessed health has been questioned by many researchers, they are important tools for evaluating population health. This is not only because of availability of the data, but also because they can capture a series of intertwined social-economic factors related to an individual’s health (Jürges, 2007; Masseria *et al*., 2007). An individual’s health is regarded as one of the significant variables explaining human happiness (Clark & Oswald, 2002).

There is increasing evidence that a high level of life satisfaction and positive emotions are associated with better health and longevity (Diener & Chan, 2011). Therefore, increased efforts have been made to develop measures for assessing well-being that constitute both human health and life satisfaction (Ryff & Singer, 1996; McGillivray, 2006; Diener *et al*., 2010). Better information about the spatial variations of population health and happiness are required to inform policy aimed at improving the health and happiness of population (National Research Council, 2001).

4.3 Data and Methods

Our selected indicators represent initial measurements of the ecological, social and economic dimensions of agroecosystem health for our framework application. Nova Scotia and Fujian provinces (Canada and China, respectively) were employed as case studies to demonstrate the use of GIS in the measurement and visual presentation of the spatial changes in those measurable variables.

4.3.1 Study Areas

4.3.2.1 Nova Scotia

Nova Scotia is one of Canada's four Atlantic Provinces (43 ° 39 '~ 47 ° 22' N latitude, 59 ° 67 ' ~ 66° 39' E longitude (Figure 4.1). It has a land area of 55,284 square kilometers. Nova Scotia lies in the mid-temperate zone, being characterized by its moderate weather, with an average annual temperature of 6.5 °C ranging from a mean temperature of 15.5 °C in summers and a mean temperature of -1.5°C (Aitkenhead-Peterson, Alexander, & Clair, 2005). Mean annual precipitation is 1,285 mm in Nova Scotia (Aitkenhead-Peterson, Alexander, & Clair, 2005). The soils in this region belong to different types of red soils, that is, soils with clay accumulation in the subsoil (Ultisols in US Soil Taxonomy). Soils in Nova Scotia are inherently weakly structured, and are naturally acidic and low in soil organic matter and nutrients (Acton and Gregorich, 1995).

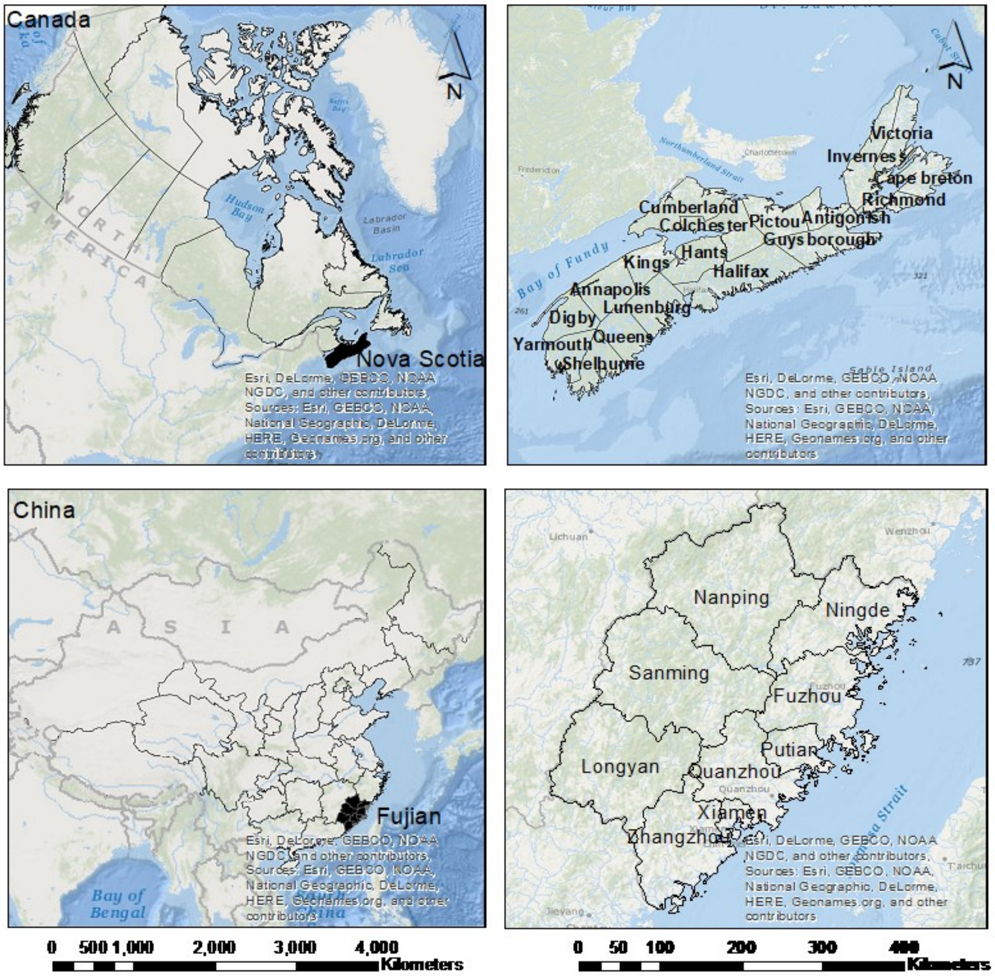

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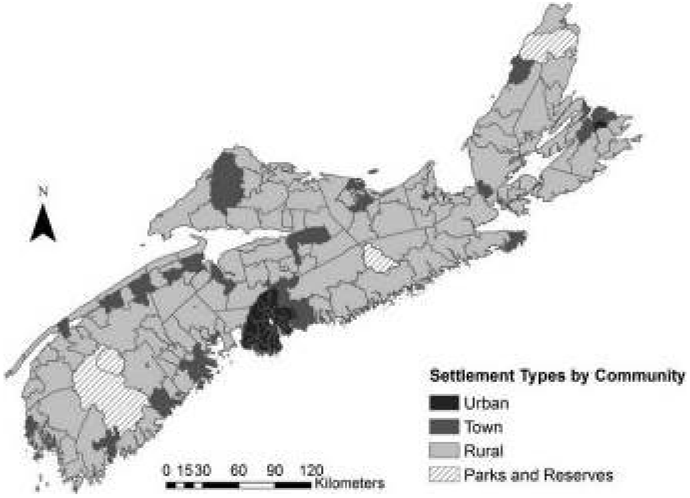
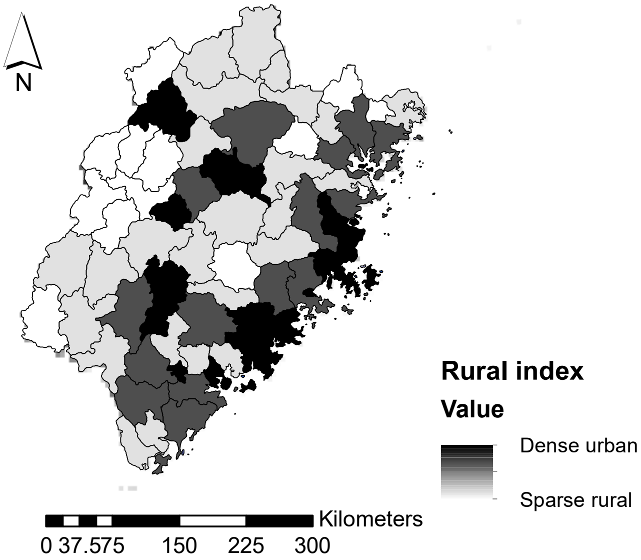
Figure 4.1 Study areas for analysis of agroecosystem health

Over the past few years, Nova Scotia's economic growth rate (0.8% in 2015) has been lower than any other province in Canada. To better understand the status of Nova Scotia in the context of Canada, it is necessary to note that the total GDP of this province ranked the 7th among the 11 provinces in Canada and contributed 2 % of Canada's GDP. The agricultural sector only contributed less than 3 % of the total GDP in Nova Scotia in recent years. Nova Scotia has a population of 923,598 residents as of 2016, and the overall population is aging with 11 out of 18 counties that senior make up 15% or more of the population in the province in 2007 (Nova Scotia Department of Seniors, 2009). The population density (17.2 persons/km^2) ranks second highest in Canada. Approximately 60% of the population live in rural parts of the province. However, there was a migration from rural to urban centers, especially to Halifax Regional Municipality and Hants, for work and services, from 2010 to 2014 (Nova Scotia Finance and Treasury Board, 2015). Figure 4.2 shows how the rural and urban areas are distributed in Nova Scotia according to Terashima (2014). Nova Scotia has recently focused on reducing poverty and improving quality of life (Myers & McGrath, 2009).



Source: from Terashima *et al*., 2014

Figure 4.2 Rural and urban areas in Nova Scotia – based on population density: 2006



(edited from the 'Rural index' values reported by Xiao *et al*., 2015)

Figure 4.3 Rural and urban areas in Fujian - 2010

4.3.2.2 Fujian Province

Fujian Province is located on the southeastern coast of China (23 ° 31 '~ 28 ° 18' N latitude, 115 ° 50 ' ~ 120 ° 43' E longitude), as presented in Figure 4.1. It covers a land area of approximately 124,000 square kilometers. Fujian Province goes through the middle and south tropical climate zone, and the average annual precipitation of this region is 1,692 mm. In addition, Fujian contains a large amount of granite rock mass and soils that are coarse-grained granite, which increases the potential for soil erosion in Fujian.

Fujian province has seen rapid growth in economic development over the past decades. Comparing to other provinces in China, Fujian's GDP ranked 11th among 31 Chinese provinces and contributed 3.84 % of the total GDP in China. The agricultural sector produced 8% of the GDP in Fujian Province at the same period. The Minnan Golden Triangle, including Xiamen, Quanzhou and Zhangzhou, plays an essential part in Fujian's economic development, with an estimated contribution of 40 % of Fujian's GDP. Fujian had a population of 38.39 million which ranked the 11th among 31 Chinese provinces as of 2015 (Fujian Province Statistics Bureau, 2016). The population growth rate is 6.2%, and the population density is 298 persons/km². Approximately 43 % of the population live in rural parts of the province. Figure 4.3 represented the spatial distribution of rural index in Fujian for the year of 2010 (Xiao *et al*., 2015). In the last decades, Fujian's is experiencing a rural-to-urban migration, driven by movement from poorer to richer areas (Chen, 2006).

4.3.2 Soil Erosion Measurement

4.3.2.1 Soil Erosion Model

Revised Universal Soil Loss Equation (RUSLE), has been widely used to predict the average annual soil loss (Renard *et al*., 1991). The in this study, the RUSLE was integrated with GIS technology to estimate soil erosion rates in Nova Scotia and Fujian province. It considers factors that interact with and affects soil erosion, including topography, climate, soil, vegetation, land use and supporting practices. With those inputs, the annual soil loss was calculated using the following equation:

$$\mathrm{A} = \mathrm{R} * \mathrm{K} * \mathrm{LS} * \mathrm{C} * \mathrm{P} \qquad \text{(Equation 4.1)}$$

Where A is Estimated rate of soil erosion (t ha^{-1} yr^{-1}), R is rainfall erosivity factor (MJ mm^{-1} ha^{-1} h^{-1} yr^{-1}), K is soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is slope length and slope steepness factor (dimensionless), C is cover management factor (dimensionless, range from 0 - 1), P is support practices factor (dimensionless, range from 0-1).

4.3.2.2 Data Source

Satellite remote sensing data, including Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM), Tropical Rainfall Measuring Mission (TRMM), and European Space Agency (ESA) land cover data, as well as the Harmonized World Soil Database (HWSD), were used for modeling soil erosion (Huffman *et al.*, 2007; Jarvis *et al.*, 2008; Bicheron *et al.*, 2008; Nachtergaele *et al.*, 2009). A 2011 Census - Boundary file of Nova Scotia was obtained from the website of Statistic Canada, and a shapefile map of Fujian is from the China Administrative Regions GIS Data: 1:1M. These shapefiles were utilized to extract the required data from DEM, Global Soil, Landcover and Rainfall Data (Appendix B Figure B1 - B4).

4.3.2.3 RUSLE Calculation

The model proposed here improved the estimation of each soil erosion factor, through applying the latest data currently and freely available for any place in the world. Each factor was estimated within the raster files in GIS environment. The geospatial resolution for the raster files is 30 m.

Monthly rainfall data for 62 observation points (climate stations) in Fujian province and 66 observation points in Nova Scotia were extracted from TRMM (3B43) database (January 2006 to January 2016). The rainfall erosivity factor (R) for selected observation points were calculated based on equations proposed by Arnoldus, 1980; Yu & Rosewell, 1996; Essel *et al.*, 2016. Then, the values of the R factor estimated were exported into the GIS, and a Kriging interpolation method was utilized to interpolate the rainfall erosivity factors of the two regions.

The data for soil properties utilized for calculating the soil erosivity factor (K) was derived from HWSD. The derived raster data contained the required information, including the percentages of clay, silt, and sand, as well as organic carbon content in soil. A textural triangle (Figure B7 in Appendix B) was used to determine the texture class of the soils in different sample locations in the two provinces. Organic carbon contents were converted to organic matter by multiplying a factor of 1.72 (Nelson & Sommers, 1982). As a result, each soil mapping unit for each one of the regions was assigned a K value, according to Roose (1996).

The SRTM database was utilized for extracting raster files for the calculation of Slope Length and Slope Steepness factor (LS). The slope steepness factor (S) was computed according to formulae proposed by Wischmeier *et al*., 2014, while slope length factor (L) was calculated according to Moore and Burc's (1992) formulas. Raster calculation of GIS was utilized to multiply L and S factor to get the LS factor values.

The land cover data were derived from the ESA land cover database (January to December 2009). Each land use category in each region was assigned a value for cover management factor (C) based on Kim *et al.*'s study in 2005. The value of support practices factor (P) for the areas with supporting practices[2] was determined, based on the relation between the supporting practice and slope in the study areas (Shin, 1999; Kim, 2006). The agricultural land area in each region was identified from the derived land cover. The slope was calculated for each area of agricultural land use. Then, all the non-agricultural areas were assigned a value of 1. The P values were assigned to agricultural land following Shin (1999) and Kim (2006)'s studies, which considers both supporting practices and slopes. In Fujian province, all three supporting practices are distributed in the agricultural land use area. Thus, the mean value of the three categories was considered to calculate the P factor values in Fujian province. With regard to Nova Scotia, strip cropping was the only supporting practice; therefore, the values for strip cropping were applied to assign P factor values in this area.

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[2] The support practice (P) in RUSLE is the ratio of soil loss with a specific practice of corresponding loss with upslope and downslope tillage. These practices principally affect erosion by modifying the glow patter, grade, or direction of the surface runoff and by reducing the amount of the rate of runoff. For cultivated land, the support practices include contouring (tillage and planting on or near the contour), strip-cropping, terracing, and subsurface drainage (Renard, 1997).

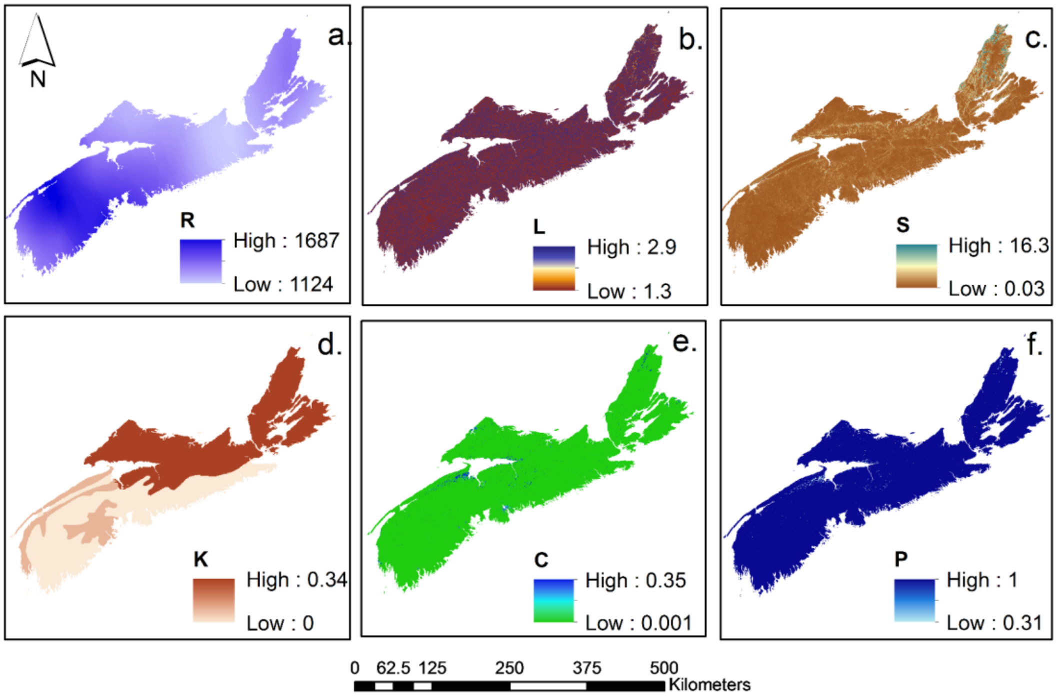

Figure 4.4 **a.** Spatial variation in the rainfall erosivity factor (R) in Nova Scotia; **b.** Spatial variation in slope length factor (L) in Nova Scotia; **c.** Spatial variation in slope steepness factor (S) in Nova Scotia; **d.** Spatial variation in soil erodibility factor (K) in Nova Scotia; **e.** Spatial variation in cover management factor (C) in Nova Scotia; **f.** Spatial variation in support practices factor (P) in Nova Scotia.

The detailed calculations of these factors are described in Appendix B. The estimated rate of soil erosion was obtained by multiplying all raster files of the five factors (R, K, LS, C and P factors), as showed in Figure 4.4 and 4.5, using the raster calculation tool of the ArcGIS. The variation in annual average soil erosion rates for 2009 was determined. GIS was utilized to present the spatial variation of estimated soil erosion in the two regions, using 2009 as the reference year.

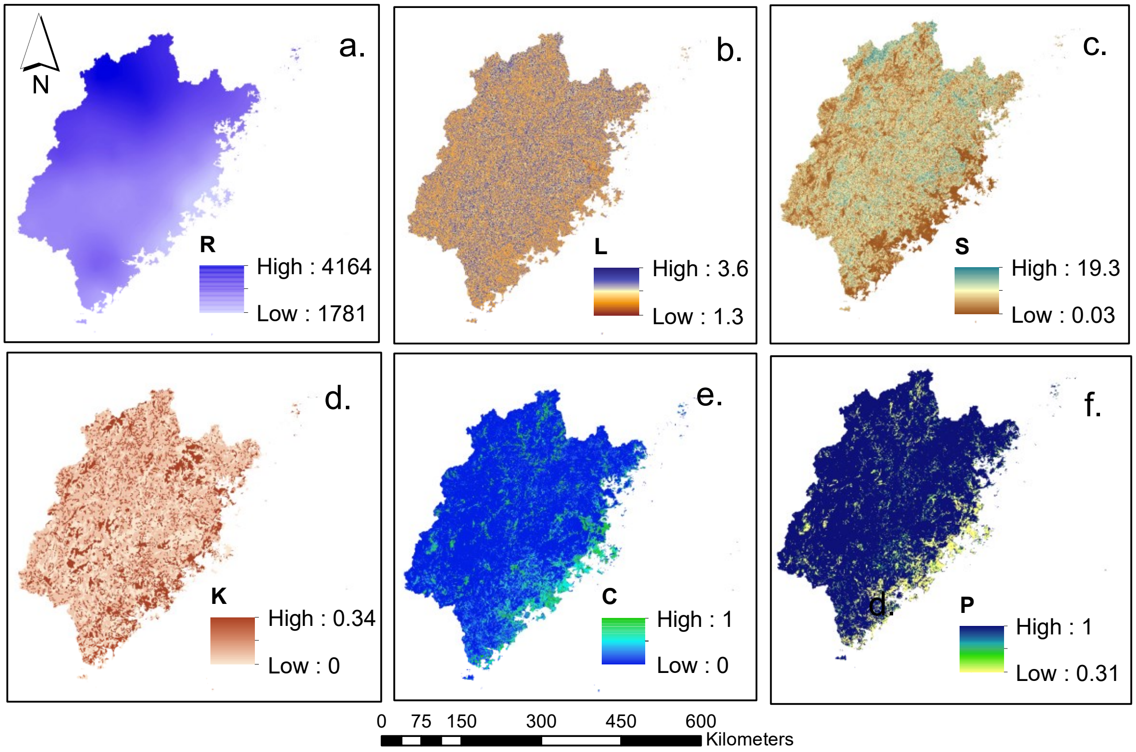

Figure 4.5 **a.** Spatial variation in the rainfall erosivity factor (R) in Fujian; **b.** Spatial variation in slope length factor (L) in Fujian; **c.** Spatial variation in slope steepness factor (S) in Fujian; **d.** Spatial variation in soil erodibility factor (K) in Fujian; **e.** Spatial variation in cover management factor (C) in Fujian; **f.** Spatial variation in support practices factor (P) in Fujian.

4.3.3 Economic Indicator - Purchasing Power Parity GDP

4.3.3.1 Data Sources

The main source of data on Fujian GDP and the population in 2010 was from Fujian Statistical Yearbook (2011). The spatial scale of geography for deriving Fujian data was county territories. The main data source for annual Nova Scotia GDP was from Statistics Canada's Table 379-0030 (2010). The Nova Scotia workforce data used for calculating the percentage each region that contributed to provincial GDP of Nova Scotia was from Canadian Census' labor force population. The level of geography for achieving Nova Scotia data was census subdivisions.

The annual average exchange rates, which were used for converting the GDP from national currency to US dollars, were obtained from the World Bank database. The data for national purchasing power parity (PPP) GDP and GDP at the official exchange rate (OER) in the two countries were also archived from World Bank database (The Word Bank, 2012).

4.3.3.1 Measurements

(1) PPP GDP

Also known as the real exchange rate, PPP is the purchasing power of a currency relative to another at current exchange rates and prices. It is the ratio of the number of units of a given country's currency necessary to buy a market basket of goods in the other country, after acquiring the other country's currency in the foreign exchange market, to the number of units of the given country's currency that would be necessary to buy that market basket directly in the given country (Erlat & Arslaner, 1997; Sarno & Taylor, 2002). The PPP GDP data are available in World Bank at national levels but not at a provincial scale. However, the PPP GDP for the provinces and their sub-regions can be calculated (Equation 4.3), based on GDP at the official exchange rate (OER) when the ratios between nation’s OER GDP and PPP GDP can be obtained (Equation 4.3). The regional GDP at the official exchange rate, both at regional and provincial levels, was calculated by using local currency GDP divided by the official exchange rate (local currency units relative to the U.S. dollar).

$GDP_{ppp} = \frac{GDP_{OER}}{R_{er}}$ (Equation 4.2)

Where: GDP_{ppp} represents the PPP GDP in the targeted region; GDP_{OER} represents the OER GDP in the targeted region; R_{er} represents the ratio for national OER GDP and national PPP GDP.

$R_{er} = \frac{GDP_{NOER}}{GDP_{NPPP}}$ (Equation 4.3)

Where: R_{er} represents the ratio for national OER GDP and national PPP GDP; GDP_{NOER} represents the national GDP at official exchange rates; GDP_{Nppp} represents the national GDP at PPP rates.

(2) GDP per head

GDP per capita is gross domestic product, based on converted PPP rates, divided by the population (Schneider *et al.*, 2010). GDP per head was calculated by using the total GDP in a region (sub-region / province) divided by the total population in a region (Equation 4.4).

$GDP_p = GDP_i / P_i$ (Equation 4.4)

Where: GDP_{ppp} represents regional GDP per head; $PPPGDP_i$ represents the regional GDP at PPP basis in the targeted area in year i; P_i represents the population in the targeted area in year$_i$.

The total GDP and population for the 119 sub-regions in Fujian were derived from Fujian Statistic Year Book. GDP data was not available for the studied Nova Scotia counties. The alternative version of regional GDP in Nova Scotia at the sub-regional level was calculated by multiplying the provincial GDP by the percent of the provincial workforce in the given regions. Then, the GDP per head for the 119 sub-regions in Fujian and 99 subdivided regions in Nova Scotia were determined via using Equation 4.2-4.5. The calculated regional GDP data for the year of 2011 were input into GIS and raster files were created for mapping the spatial changes of GDP per head.

4.3.4 Human Health and Happiness

4.3.4.1 Data Source

The analysis of human health and happiness in Fujian and Nova Scotia were based on microdata collected from nationwide surveys in China and Canada (Canadian Community Health Survey, 2010; National Survey Research Center at Renmin University of China, 2010). The data for analyzing population health and happiness in Nova Scotia were derived from Statistics Canada's Canadian Community Health Survey (CCHS). The national Chinese General Social Survey (CGSS) survey data were derived and utilized for analysis of human happiness and health in Fujian. However, the CGSS data is only available at the provincial level, rather than at the sub-regional level. The data for health categories of people older than 60 years old was derived from the 2010 China population census. This was utilized for analyzing the regional human health and estimating happiness in Fujian at a sub-regional level.

4.3.4.2 Measures and Social-Demographic Attributes

One of the most important variables in our analysis is that of perceived health. Perceived overall health in both CGSS and CCHS were measured by requesting respondents to rate their health using a 5 or 10-point scale. The health data for both regions were recorded to make all them both 3 points scales (3=excellent, good or very good, 2=fair, 1=poor or very poor). The variable of happiness was measured by asking respondents to rate their life satisfaction or living condition by using a hierarchical scale. Either a five or eleven-point scale was utilized in these measurements. The happiness data for both regions were coded to make all of 3 point scales (3=very satisfied or satisfied, 2=neither satisfied nor dissatisfied, 1=dissatisfied or very dissatisfied). The percentages of people who reported being healthy (happy) or fair (neither happy nor unhappy) were calculated for analysis of spatial variation of health and happiness across 99 sub-regions in Nova Scotia in 2010. The same calculations were also done at the provincial scale in Fujian.

Social-demographic variables for Fujian, including gender, age, marital status, education level household registration status (rural or urban) and income level, along with the self-reported health and happiness, were extracted from the CGSS survey data. Logistic Regression was further conducted to determine if the odds of observing response category of happiness in Fujian could be explained by the variation in human health, gender, income, education, education level, marital status and household registration status. Thus, the happiness measurements were selected as the dependent variable (1 = happy or neither happy nor unhappy, 0 = unhappy) and the socio-demographic factors were set as the independent variables. The human health predictor was coded as 1 = healthy or fair, 0 = unhappy; the gender predictor was coded as 1 = female and 0 = male; the age predictor was coded as 1 = older than 50 and 0 = younger than 50; the educational level predictor was coded as 1 = higher than secondary education and 0 = lower than secondary education; marital status predictor was coded as 1 = married, single or common-law relationship and 0 = separated and widowed; income level predictor was coded as 1= more than RMB 40, 000 and 0 = less than RMB 40,000; household registration status was coded as 1 = agricultural household registration status and 0 = non-agricultural registration status. The traditional 0.05 criterion of statistical significance was utilized for the tests. The Logistic Regression model, established as follows, were utilized to predict happiness of each sub-region in Fujian.

$\log(p(HA) = \log\left[\frac{p(HA)}{1-p(HA)}\right] = 1.760 + 1.636 * HE + 0.171 * HO$ (Equation 4.5)

Then, p can be calculated by the following formula:

$$p = \frac{e^{1.760 + 1.636 * HE + .171\,HO}}{1 + e^{1.760 + 1.636 * HE + .171\,HO}} \text{ (Equation 4.6)}$$

Where: *HA* represents the percentages in happy or neither happy nor unhappy category; *HE* represents the percentages in health or fair category; *HO* represents the percentages in household registration; p represents the probability that a case is in happy or neither happy nor unhappy category; e represents the base of natural logarithms (approx. 2.72).

Using the data of percentages of health categories (health categories of people older than 60 years old was derived from the 2010 China population census) and household registration status categories, the Fujian regional percentages of happiness for each sub-region was estimated, based on Equation 4.6.

4.3.4.3 Spatial Variation

Taking 99 subdivided regions in Nova Scotia and 119 regions in Fujian as study units, the spatial pattern of changes in self-reported human health and happiness were studied. Taking 2010 as the reference year, the percentages of people who reported being healthy (happy) or fair (neither happy nor unhappy) were calculated for each studied sub-region. The computed values were imported into GIS, and raster files were created to visually present the spatial distribution of human health and happiness in the two provinces.

4.3.5 Geospatial and Statistical Analysis

The "Zonal Statistics as a Table" tool in GIS was used to further analyze the spatial distribution of all measured indicators: human happiness and health, soil erosion, and GDP per head. The mean value of each zone for the three selected indicators was obtained as a result of the zonal statistical analysis. To provide a coarser basis for spatial analysis at administration districts level in a big picture, nine political districts in Fujian and 18 counties in Nova Scotia were utilized as zones. Then, 119 sub-regions in Fujian and 99 sub-regions in Nova Scotia were utilized as zones units; the mean values for these sub-regions were utilized for providing more details for spatial analysis of the indicators.

4.4 Results

4.4.1 Spatial Variation in Agroecosystem Health Indicators in Nova Scotia

Figure 4.6 graphically provides the distribution of these indicators over the province of Nova Scotia. The higher values for soil erosion rates were found in the northeast coastal area of Nova Scotia (including all of Cape Breton Island), while lower values of soil erosion rates were mainly observed in southwest coastal areas (Figure 4.6: a). Nova Scotia had a spatial distribution of soil erosion decreasing from northeast to southwest, which approximately corresponds with elevation. The result from zonal statistic indicated that three counties which had the highest mean values of soil erosion in Nova Scotia, were Inverness (1.42), Victoria (0.82), and Colchester (0.86) counties. The county of Shelburne was observed to have the lowest calculated mean value of annual soil rate at 0.01 t ha^{-1} yr^{-1} (Table 4.1).

The spatial pattern of regional GDP in Nova Scotia was directly associated with the locations of urban areas. The results of the spatial analysis showed that the central region of Nova Scotia, especially Halifax, was recorded as having the highest GDP per head (49830), while western Nova Scotia was found to be lowest (Richmond, 35206) and eastern Nova Scotia was between these extremes, as seen in Figure 4.6: b. In 2011, there were seven regions where GDP per head was less than the regional average value of 12040, namely: Digby, Guysborough, Cape Breton, Shelburne, Queens, Annapolis, Richmond counties. Those regions are primarily located on the east coast of Nova Scotia. Halifax, Colchester, and Hants were the top three counties that recorded the highest GDP per head that year. Other counties had their regional GDP per head slightly higher than the average.

Table 4.1 Zonal statistic for selected indicators in Nova Scotia

General Location in Province	County	Soil erosion ($t\ ha^{-1}\ yr^{-1}$)	GDP per head (Intl $)	Human health (%)	Human happiness (%)
East	Victoria	0.82	45,384	94	97
East	Inverness	1.42	43,797	94	96
East	Cape Breton	0.35	40,087	94	97
East	Richmond	0.50	35,206	95	96
East	Antigonish	0.53	48,463	95	96
East	Guysborough	0.17	40,616	95	96
East	Pictou	0.54	45,506	95	96
Center	Colchester	0.86	45,839	94	95
Center	Cumberland	0.57	44,782	94	95
Center	Hants	0.64	47,541	96	96
Center	Halifax	0.18	49,830	98	98
Center	Kings	0.21	44,031	97	99
West	Lunenburg	0.11	43,600	95	97
West	Annapolis	0.08	37,579	97	99
West	Queens	0.04	38,327	95	97
West	Digby	0.06	42,417	95	97
West	Yarmouth	0.04	45,217	95	97
West	Shelburne	0.02	38,619	95	97

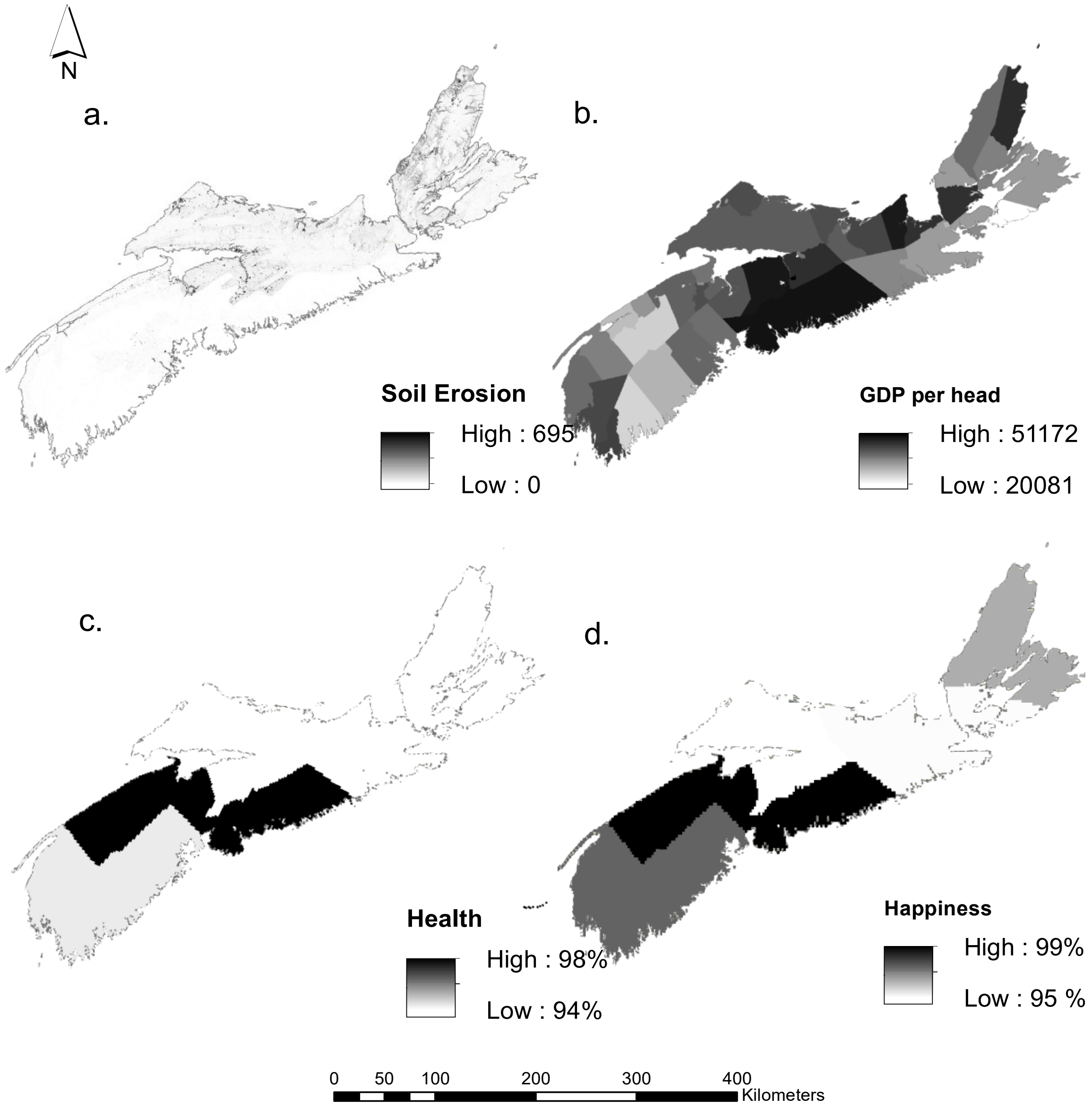

Figure 4.6 **a.** Spatial variation in the estimated rate of soil erosion in Nova Scotia; **b.** Spatial variation in GDP per head in Nova Scotia; **c.** Spatial variation in human health in Nova Scotia; **d.** Spatial variation in human happiness in Nova Scotia

The spatial distribution of Nova Scotia respondents reporting being healthy or fair, as well as that reporting being happy or “neither happy nor unhappy,” are presented in Figure 4.6:c and 4.6: d. The results indicate that dwellers in Halifax, Kings, and Annapolis counties more frequently perceived themselves as “being healthy” or “being fair” (98% - 99%), while the Cumberland and Colchester residents had lower health scores (approximately 95% rating their health as healthy or fair. Other regions had the percentages of the reported health condition, ranging from 95% to 97%.

The result from the spatial analysis of happiness showed a pattern similar to that of health value. Halifax, Kings, and Annapolis counties were the areas with the highest percentage (98% - 99%) of happy people, compared with other areas. These counties were also found to rank highest in terms of self-reported health. On the other hand, differences in the percentage of self-reported happiness among other counties were not very high and the percentages varied from 94% to 96%. Among those counties, Cumberland and Colchester had the lowest percentages of people reported being happy and "neither happy nor unhappy."

4.4.2 Spatial Variation in Agroecosystem Health Indicators in Fujian

Figure 4.7 graphically provides the spatial distribution of these indicators over the province of Fujian. The mainland of the east coast of Fujian had the highest average soil erosion rates (Quanzhou, 190.53) and those high rates extended throughout the mainland from northeast Fujian to southwest Fujian (Figure 4.7: a). The result from Zonal Statistics shows that the two districts which had the highest mean values of soil erosion in Fujian were Quanzhou and Nanping while Putian and Longyan were observed with the lowest mean value of annual soil rate at 84.37 t ha^{-1} yr^{-1} and 81.54 t ha^{-1} yr^{-1}, respectively (Table 4.2). Moreover, other counties had soil erosion rates that ranged from 88.92 to 137.13 t ha^{-1} yr^{-1}.

The spatial pattern of regional GDP in Fujian mirrors its rural and urban distribution. The results indicated that the high-value cluster was concentrated in the coastal area and the low value clustered in the inland area of Fujian. The zonal statistic results indicated that Fujian province can be divided into three categories, according to the estimated GDP per head: coastal developed regions (including Xiamen, Fuzhou and Quanzhou); less developed coastal areas (including Ningde, Putian and Zhangzhou) and less developed inland areas (including Nanping, Longyan and Sanming). With the highest GDP per head, Xiamen (20066), Fuzhou (12978) and Quanzhou (12418) were the centers of Fujian's economic development (Figure 4.7: b). The values of GPD per head tended to consistently decline as the distance from the golden triangle increased.

Table 4.2 Zonal statistic for selected indicators in Fujian

Location	City	Soil erosion ($t\ ha^{-1}\ yr^{-1}$)	GDP per head (Intl $)	Human health (%)	Human happiness (%)
Southeast	Fuzhou	130.13	12,978	87	88
Southwest	Longyan	81.54	12,743	88	88
Northeast	Nanping	154.85	9,413	88	89
Northeast	Ningde	137.13	9,050	82	87
Southeast	Putian	84.37	9,476	89	87
Southeast	Quanzhou	190.53	12,418	88	87
Northwest	Sanming	88.92	12,921	90	89
Southeast	Xiamen	102.47	20,066	93	89
Southeast	Zhangzhou	132.96	9,292	90	88

The distribution pattern for human happiness in Fujian showed a similar spatial distribution as that previously noted for GDP per head. The centers for Fujian's economic development (Xiamen, Fuzhou, and Quanzhou) were observed to have residents who reported relatively higher percentages in terms of both health and human happiness (Figure 4.7: c and Figure 4.7: d). The percentages appeared to consistently decrease as the distance from these three districts increased. The results show that Xiamen ranked the first for both happiness and health (93% & 89%), while Ningde ranked the last for those aspects of agroecosystem traits (87% & 82%). However, the maps revealed a difference in the spatial pattern of human happiness and health in Fujian. A high-value cluster of self-reported human health was found in the coastal area peripheral areas, including northeast part of Nanping, northwest part of Longyan and most area of Sanming. Interestingly, the self-reported happiness was found at a relatively lower level among these sub-regions.

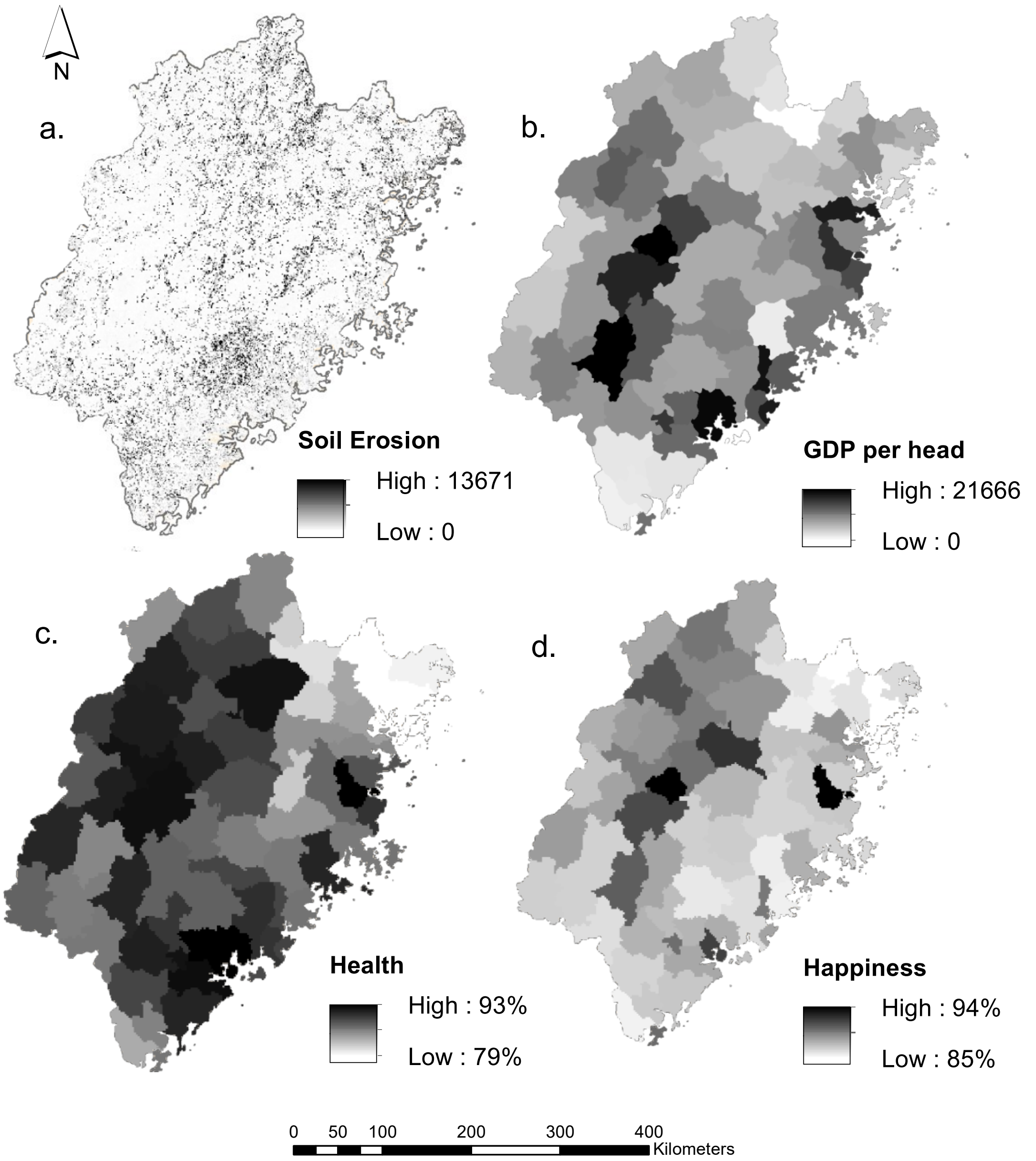

Figure 4.7 **a.** Spatial variation in the estimated rate of soil erosion in Fujian; **b.** Spatial variation in GDP per head in Fujian; **c.** Spatial variation in human health in Fujian; **d.** Spatial variation in human happiness in Fujian

4.5 Discussion

Using two case studies (North America and Asia), the present work sought to explore the use of GIS in monitoring the ecological, social, economic components of agroecosystem health. The change in the key indicators over space within the case study regions was examined.

4.5.1 Exploiting GIS in Agroecosystem Health Evaluation

The integration of remote sensing data and census data in a GIS framework has been achieved in this study, at both sub-regional and provincial scale in a global context, employing cases studies from a developed country and a developing country. Using the spatial analysis tool of GIS, agroecosystem health was evaluated and analyzed, geographically, in a relatively easy way. The visual representation of GIS maps presented in this study is useful in highlighting the differences in biophysical and social-economic conditions of agroecosystem health across the case study area. This has been a promising feature that links linked GIS and system modeling. There have been many studies have also illustrated this point. Aspinall & Pearson (2000) confirmed that GIS is an efficient tool to develop and used it in calculating a series of indicators designed for geographical monitoring of environmental health and change at regional scales. It is believed by Vadrevu *et al*. (2008) that the biophysical features of an agroecosystem have become more easily measurable as extensive georeferenced data are becoming more readily available. The advancement of GIS technologies and the exploitation of remote sensing data has been gradually adopted and used to facilitate multidisciplinary ecosystem evaluation in policy making (Malaysia, Phua & Minowa, 2005; Yu *et al*., 2013). This study, therefore, highlighted that that GIS could be an invaluable tool in multi-criteria assessment which incorporates remote sensing data and census data.

4.5.2 Spatial Changes in Agroecosystem Health Indicators

The geographic distribution of estimated soil erosion exhibited a cluster of high values in the northeast coastal area of Nova Scotia decreasing towards the southwest. According to the estimated soil erosion factors, the high value of soil erodibility factor (K) clustered in the north and central regions in Nova Scotia, since the soil textures were sandy loam (0.12 t ha^{-1} MJ^{-1} mm^{-1}) and loam (0.34 t ha^{-1} MJ^{-1} mm^{-1}). The northwest and northern parts of Nova Scotia, in addition, had the relative greater values for slope length and slope steepness (LS) factor, which is due to the high elevation values. The most vulnerable type of land with respect to soil erosion, as Lech-hab *et al*. claimed (2015), are bare land, urban area and agricultural land and the least vulnerable one were the forests. The northern coastal area had a relatively higher proportion of land under agricultural production, which increases the vulnerability of soil.

The results show that central Nova Scotia, especially Halifax, had a focused concentration of high GDP per head and a high percentage of the happy and healthy population. The eastern parts of Nova Scotia were found to have a low values cluster. The regional difference in the GDP per head was perhaps caused primarily by local and external supply and demand factors. The most obvious factors to consider in the regional economic development, from the aspect of demand and labor resources are Nova Scotia's population size. More than 70% of the population resides in central Nova Scotia, with the Halifax area accounting for 40% of total central Nova Scotia population. This relatively higher population density leads to more workforce available, partially explaining the higher GDP per head in the middle of Nova Scotia, compared with other regions. Sharpe & de Avillez, 2012 pointed out that capital investment, particularly machinery and equipment infrastructure and R&D, contributed to different levels of regional GDP per head in Nova Scotia. In agree with Millward (2005), the two key factors identified for low-income regions are resource dependency and isolation. For instance, Cape Breton Highlands and some districts in the southeast that are distant to a larger urban center and heavy economic dependence on resources industries.

This spatial analysis shows that Halifax was ranked at the top among all the cities in Nova Scotia for both human happiness and health. The regional difference in human health and happiness is not only influenced by economic performance but also affected by a quite complex interaction of social and environmental factors. These vary from public facilities, safety and security, sense of community, social support, corruption, generosity, and freedom to make life choices. Central Nova Scotia, especially metro Halifax, had advantages on these aspects over other regions in Nova Scotia. In addition, during the period examined in this study, Halifax has the youngest population among the counties in the province. In 2007, seniors accounted for 10% of Halifax County's population, while 11 of the 18 counties had a seniors' population that contributed 15% or more of the population (Nova Scotia Department of Seniors, 2009). Unexpectedly, in Colchester and Cumberland human health and happiness were not high when GDP per head was relatively higher. It is consistent with the result presented in the Nova Scotia Health Profiles published by Department of Health and Wellness (2015) that these two regions had relative lower self-reported health. This probably due to the relatively larger proportion of aging people in these two regions. It is notable that, in 2007, Cumberland had the largest share of senior population among the counties in the province (Nova Scotia Department of Seniors, 2009).

The results suggested that, in Fujian, the mainland of eastern coastal areas had higher rates of soil erosion, compared with the northwest inner region. This is supported by Chen, Wu and Chen (2007) and their finding that coastal areas in Fujian are the most eroded place among province. One important factor that to the variations in soil erosion is that of human activities. In coastal areas with a higher level of urbanization and economic development, the land use has been greatly changed by humans. Not only the traditional agricultural land is primarily distributed in this area, but the most economically developed cities and towns that were recognized as urban areas, cluster here as well. In contrast, other inland areas in Fujian, covering a greater percentage in a rural area or less developed small towns had less human-generated activity and interference with the natural landscape. For example, Sanming has a great coverage of forest, and 82.5% of the land is used for forestry.

The spatial distribution in GDP per head in Fujian revealed that a high-value cluster was concentrated in the coastal area, especially in southeast coastal areas that most urban area takes over, and the low-value cluster in the northern inland that has a higher proportion of rural area. This is consistent with the findings from Chen (2006) and Zhan *et al.* (2016) that a high-value cluster area existed in Xiamen Fuzhou and Quanzhou that are within the developed coastal areas, On the other hand, a low-value cluster was found in inland regions in Fujian. The superior prosperity of economic development southern Fujian is due mainly to their advantageous nature and political conditions. Southeast coastal area faces Taiwan on the east and Hong Kong and Macao on the south. Also, the national government has given out the preferential policies that give an economic advantage of proximity to these trading areas in the southeast. This is especially true for Xiamen which was granted the administrative permissions that are the same as at a provincial level. This resulted in a stronger free market system with increasing exchange of foreign capital and technologies. In contrast, the economic development northwest Fujian mainland was slower mainly because of its incomplete market system and unreasonable economic structure. The agricultural sector contributed to a larger part, while industry and service sectors were less developed in those regions, compared with southeast of Fujian (Chen, 2006). In addition, the migration of rural labor into the urban areas can explain the difference between Northern Fujian and Southern Fujian, with regards to the economic development.

Moreover, the spatial pattern of human happiness and health in Fujian displayed a similar spatial distribution that noted for GDP per head. The gap between happy and healthy regions could be explained by the difference between urban and rural areas for the economic developments and social supports. These findings are supported by Treiman (2012), who reported that disparities in well-being remain substantial between the rural and urban categories. This divergence is largely due to the rural-urban registration system in China. Whether a person has a non-rural household registration has a great impact on the educational resources, job opportunities and social welfare a person can obtain, which is positively related to human health and happiness (Treiman, 2012). The findings indicted unexpected differences in spatial patterns between self-related human happiness and human health in Fujian. This suggested that the GDP indicator has a two-sided nature. On the one hand, rapid economic modernization and urbanization have appeared to increase health and happiness while, on the other hand, has caused serious environmental problems in urban areas and some suburb, including pollution and food security, shortages of resources and energy. In fact, it is also noted by Smyth *et al.* (2008) that in cities atmospheric pollution, traffic congestion and that are prone to a high rate of environmental disasters, people tended to have lower levels of health, compared with those in cities with greater access to grassland and superior public facility.

4.5.3 Implications and Limitation

This research has focused on the multi-dimensional evaluation of agroecosystem health at multiple scales (provincial and sub-regional scales). The indicators presented here are not new. Rather the unique contribution offered by this work is the GIS-associated link and initiative to combine remote sensing data and census data in agroecosystem assessment in a global context, using Nova Scotia and Fujian as case studies. The studied spatial pattern of agroecosystem health, utilizing soil erosion, GDP per head, and human happiness and health as key indicators, has provided new sight on how agroecosystem health varied spatially for the ecology, economic and social aspects. This is potentially valuable for international comparison and cross-cultural studies by enriching the evidence on how developed and developing countries differ in how biophysical and social components changed in space.

The GIS-based analysis of the spatial difference in agroecosystem health indicators can be valuable in identifying the strengths and opportunities of each sub-region. The new sights provided for Fujian and Nova Scotia can be useful for policy decision maker to prioritize different regions with the most appropriate regional policies that can enhance agroecosystem health. It has also unearthed the need/opportunity to consider these results within the cultural context and norms of different societies.

This study has enhanced the soil erosion modeling by utilizing a set of remote sensing databases which are available at a world scale. However, like any other study based on remote sensing data, the spatial resolution of the remote sensing data needs to be further improved. The estimation of soil erosion was significantly affected by the landover types. In particular, the estimates are sensitive to forest coverage and tree species, since the cover management factor (C factors) vary for different coverages with various species. It would be useful to exanimate the influence of various types of Landover on soil erosion, for generating a higher classification accuracy of C values that could be applied to produce a higher level of accuracy of the evaluation. The study also indicated that agricultural land use has an important impact on soil erosion by affecting support practice factor (P factor). It would be useful to drill down into the types of cropping systems and types of agriculture (cattle, etc) and to explore and understand the conventional/new land management and cover crop practices.

One of the limitations of the study is the lack of direct data for the regional indicators. For example, the regional data for self-reported health in Fujian was not available; a logistic regression model, however, was created to estimate the regional self-reported health. Given the nature of agroecosystem, it is reasonable to involve many approaches from multidisciplinary studies. However, it is not possible to cover all aspects of the complexity of agroecosystem in this single study. It is feasible to include more indicators when more data are available at multiple scales. The scope of study on multi-indicator evaluation could be extended to rural areas or farmland scale.

CHAPTER 5 EMPIRICAL EVALUATION OF AGROECOSYSTEM HEALTH COMBINING ECOLOGICAL-SOCIAL-ECONOMIC COMPONENTS: A COMPARISON BETWEEN NOVA SCOTIA AND FUJIAN

5.1 Introduction

There is increasing evidence that a growing diversity and intensity of human activities, particularly for agricultural practices, have substantially changed ecosystems, and many times, in negative ways (Vitousek *et al*., 1997; Ceballos *et al*., 2015). A consciousness of the fragility of the world's ecosystem has grown, leading to a growing number of studies on the relationships between social-ecological development and environmental conservation (Vitousek *et al*.,1997; Ceballos *et al*., 2015). The current incredible achievement in agricultural yields and accompanying economic development has often come at a cost to other services and benefits provided by the ecosystems, particularly clean water and beneficial soil; this is accompanied by a considerable degradation of the worldwide environmental condition (Olsson & Ardö, 2002; Bakr *et al*., 2012; Foley *et al*., 2011; El-Sharkawy, 2014; Crosson & Anderson, 2014). Sustaining agricultural production while preserving or improving the status of environmental conditions and human livelihood has been one of the actual challenges for stakeholders, researchers and policymakers (Olsson & Ardö, 2002; Tilman *et al*., 2002; Bohlen & House, 2009; Tscharntke, 2012; Bakr *et al*., 2012; El-Sharkawy, 2014; Crosson & Anderson, 2014). This reinforces the need for a multidisciplinary approach to understand this challenge and to develop ecological and socio-economic insights to gauge the impact of current practices and policies and to explore options for sustainable development (López-Ridaura *et al*., 2002).

Agroecology has emerged as an integrative discipline that acknowledges both the ecological and the social-economic context of the agricultural system (Okey, 1998; Dalgaard, 2003). An agroecosystem is a fundamental unit of the discipline of Agroecology. As a spatially and functionally coherent unit, with agricultural activities involved, an agroecosystem incorporates the living and nonliving parts associated with that unit, as well as their conditions and inter-connections (Conway, 1984; Smit *et al*., 1998). Agroecosystems can be described as fields or farm systems, or in a broader context as communities or watersheds, or more comprehensively on a provincial or even worldwide scale (Conway, 1986; Altieri, 1999; Bohlen & House, 2009). As human-centered ecosystems, agroecosystems have been dominated and controlled by humans for the purpose producing all kinds of products, including food, raw materials, fresh water, minerals, natural resources, and energy, as well as being used simultaneously for human settlements. Agroecosystems play important roles in environmental and social services benefiting humankind (Zhang & Rao, 2003; Porter *et al*., 2009), although these values are not usually well recognized by societies, as they are indirect, non-market ecosystem services. Agroecosystems are not self-sustaining, as they are affected by both internal and external ecological and socio-economic components, and all play parts in the overall performance and productivity of the whole system (Conway, 1987; Marten, 1988; Vadrevu *et al*.,2008).

Okey (1996) introduced "health" as a concept that is normally used to describe an organism and applied this concept from medical science to agroecosystem studies. This has generated a conceptual approach that allows for better understanding of the multidimensional agroecosystem goals and providing of policy recommendations. A healthy agroecosystem is defined as one managed in a socially responsible manner, economically viable that is environmentally sustainable for the present and future generations (Gitau *et al*., 2008; Peterson, 2017). Yiridoe and Weersink (1997) noticed that an agroecosystem is "healthy" with respect to the sustainability of its environmental and social-economic dimensions. The model of agroecosystem health can provide an integrative approach that assesses the status and performance of agroecosystem, simultaneously considering multiple components from the biophysical and social-economic aspects. Since agroecosystem components vary geologically and over time, and certainly are socially diverse among various national contexts, the health of agroecosystems also varies over time and geographical dimensions. The dynamic complexity of agroecosystem health suggests a prioritization for the multidimensional attributes of agroecosystems or how these attributes in space and time should be balanced (Vadrevu *et al*.,2008).

Within the associated literature endeavors to seek a holistic perspective were made, using both quantitative and qualitative approaches in the study of the spatial and temporal changes of agroecosystem health (Yiridoe and Weersink, 1997; Xu & Mage, 2001; Vadrevu *et al*.,2008; Hoy, 2015; Peterson *et al*., 2017). There are three main tenets in agroecosystem health research. One tenet is the identification of a number of properties or characteristics that includes sustainability, resilience, equitability, self-organization, diversity and productivity, as bases for describing and understanding the condition and function of agroecosystem (Conway, 1985; 1987; Okay, 1996; Xu & Mage, 2001; Hoy, 2015). Secondly, the investigation of "stress/pressure" and "effect/impacts" of stress on agroecosystem: focusing on cumulative impacts of stresses both across regions and over time, by means of a general stress-process-response model (Bradshaw & Smit, 1997; Fuhrer, 2003; Xu & Merge, 2001; Sharma & Gobi, 2016); and finally, model of the utilization of aggregated indices for agroecosystem health/sustainability analysis based on a list of indicator or variables, using a system approach (Rao & Rogers, 2006; Vadrevu *et al*.,2008). This holistic approach has been applied to practice at different scales (e.g., field, farm, landscape, regions, nations). Most of the definitions of agroecosystem health emphasize both biophysical and socioeconomic dimensions (Vadrevu *et al*.,2008; Hoy, 2015; Peterson *et al*., 2017). However, in the literature, the combination of ecological-social-economic components into agroecosystem health assessment at a larger regional scale is still less well developed (Xu & Merge, 2001). Efforts have been made to implement an integrative evaluation of agroecosystems that incorporates various biophysical and social-economic indicators (Xu & Merge, 2001; Rao & Rogers, 2006; Vadrevu *et al*.,2008), but little empirical work has been conducted, combining all three components in agroecosystem health assessment on a larger regional scale. Moreover, little research has compared agroecosystems among different regions or countries in space and time in a global context.

Based on survey data and preliminary analysis presented in Chapter 3, soil erosion, GDP, and human happiness and health were identified as key indicators, from ecological, economic and social aspects, respectively. It would be ideal to use multiple indicators from each discipline, but here only one common indicator for each discipline was used as a starting point in building a model for evaluating ecosystem health in a larger scale in a global context. The provinces of Fujian and Nova Scotia have different levels of overall economic development, different cultural values, as well as contrasting political and social systems. There are, however, similarities in geographic conditions such as coverage of forest and biodiversity.

This chapter, therefore, presents an empirical study to compare agroecosystem health between Nova Scotia and Fujian, combining ecological, economic, and social components. The methodology of this study will use a multiple criteria analysis relying on GIS to demonstrate an interdisciplinary research approach for agroecosystem assessment at a provincial scale in a global context. This study addresses the following two questions: (i) How can GIS be utilized for combining ecological, social, economic components of agroecosystem health on a large scale in a global context; (ii) how, do the three selected indicators (soil erosion, GDP per head, and human happiness and health) and the agroecosystem health index derived based on an aggregation of these indicators, differ in the two study areas?

5.2 Data and Methods

5.2.1 Selected Agroecosystem Health Indicators

5.2.1.1 Ecological Indicator - Soil erosion

Excessive soil erosion not only interferes with agricultural production but also causes serious environmental problems, such as ecological collapse due to the loss of organic matter and nutrient-rich upper soil layers; desertification; sedimentation and pollution of waterways due to large amounts of transported sediment and nutrients (Blanco *et al*., 2010; Toy *et al*., 2002). In this study, soil erosion was the ecological factor selected for comparing agroecosystem health between the two study areas, from the perspective of ecology.

Data developed using the Revised Universal Soil Loss Equation RUSLE (Renard *et al*., 1991) was compared using GIS technology to estimate soil erosion rates in Nova Scotia and Fujian Province. Climatic conditions, soil, vegetation, support practices and topographic characteristics, were considered for the estimation. This study improved the estimation of each soil erosion factor in the equation, compared with previously reported research, through applying the latest data currently and freely available for anywhere in the world.

$$A = R * K * LS * C * P \qquad \text{(Equation 5.1)}$$

Where A is the estimated rate of soil erosion (t ha^{-1} yr^{-1}), R is rainfall erosivity factor (MJ mm^{-1} ha^{-1} h^{-1} yr^{-1}), K is soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is slope length and slope steepness factor (dimensionless), C is cover management factor (dimensionless, range from 0 - 1), P is support practices factor (dimensionless, range from 0-1).

Rainfall erosivity is an important parameter for soil erosion assessment. It reflects the effect of rainfall intensity and amount on soil erosion (Essel *et al*., 2016). Modified Fournier's index was utilized to calculate R factor (Arnoldus, 1980; Yu & Rosewell, 1996; Essel *et al*., 2016), which was based on readily available monthly rainfall data. The R factor for the period 1998–2016 was calculated using monthly rainfall data for 62 observation points (climate stations) in Fujian province and for 66 observation points in Nova Scotia that were derived from Tropical Rainfall Measuring Mission (TRMM) 3B43 (Huffman *et al*., 2007). The Kriging interpolation method was utilized to estimate the rainfall erosivity factor based on exported values of the R factor for the observation units.

The soil erodibility factor represents the inherent erodibility of soil textural classes with a different structure, organic matter, and permeability (Mitchell *et al*., 1980). Soil data was from the Harmonized World Soil Database (HWSD) using the percentages of clay, silt, and sand, as well as organic carbon content in soil (Nachtergaele *et al*., 2009). The texture classes of the soils in different sample locations in the two provinces were determined using a textural triangle (Figure B7 in Appendix B). Organic carbon contents were converted to organic matter by multiplying by a factor of 1.72 (Nelson & Sommers, 1982). Following the approach of Roose (1996), a K value was assigned to each soil mapping unit for each of the sub-regions.

The slope length and steepness (LS) factor accounts for the effect of terrain on erosion, and includes slope steepness (S) and slope length (L) factors. Data on topographic characteristics were derived from the Radar Topographic Mission (SRTM) Digital Elevation Model (Jarvis *et al*., 2008). The S factor was calculated according to formulae proposed by Wischmeier *et al*., 2014, while the L factor was computed according to Moore and Burc's (1992) formulas. L and S factors were multiplied to obtain the LS factor values based on raster calculation of GIS.

The C factor is used to determine the effect of land use types and land cover percentage on soil erosion rate (Renard *et al*., 1997). The P factor is defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with straight row upslope and downslope tillage. European Space Agency (ESA) land cover data (Bicheron *et al*., 2008) were utilized to determine C and P factors for the years of 2006 and 2009. C values were assigned to different land use categories in each region according to Kim *et al*.'s study in 2005. The P value of the areas with supporting practices was determined based on the relationship between the supporting practice and slope in the study areas (Shin, 1999; Kim, 2006).

The calculations of these soil erosion factors (R, K, LS, C and P factors) are described in detail in Appendix B. The estimated soil loss was obtained by multiplying all raster files of the five factors, using raster calculation in ArcGIS. The annual average soil erosion rates were estimated for the years of 2006 and 2009. The geospatial resolution for the raster files was 30 m.

5.2.1.2 Economic Indicator - Purchasing Power Parity GDP per head

Purchasing power parity (PPP) is also known as the real exchange rate, which is a statistic widely used for comparisons of GDP between countries. PPP is the purchasing power of a currency relative to another at current existing exchange rates and prices (Erlat & Arslaner, 1997; Sarno & Taylor, 2002). PPP rate is the ratio of the number of units of a given country's currency necessary to buy a market basket of goods in the other country, after acquiring the other country's currency in the foreign exchange market, to the number of units of the given country's currency that would be necessary to buy that market basket directly in the given country (Erlat & Arslaner, 1997; Sarno & Taylor, 2002).

The Gross Domestic Product (GDP) per head is calculated as the gross domestic product divided by the population (Schneider *et al*., 2010). PPP based GDP per head was selected as the key economic indicator in this study. The GDP per head was calculated as follows: GDP on a PPP basis divided by the total population at both the provincial and sub-regional level (Equation 5.2).

$GDP_{ppp} = PPPGDP_i \,/ P_{\,i}$ (Equation 5.2)

Where: GDP_{ppp} represents regional GDP per head at PPP basis; $PPPGDP_i$ represents the regional GDP at PPP basis in the year i; P_i represents the population in the region in year$_i$.

For the provincial level, the temporal changes in GDP per head were studied, from 1998 to 2015, in the two provinces. For the sub-regional level, 2010 was utilized as the reference year to study the spatial variation of GDP per head across sub-regions (99 sub-regions for Nova Scotia and 119 for Fujian).

Since the GDP data were collected in local currency rather than in a comparable PPP basis, the local currency GDP was used to create an internationally comparable PPP based GDP. First, the regional GDP at official exchange rate was calculated by using local currency GDP divided by the official exchange rates (local currency units relative to the U.S. dollar), according to Equation 5.3. GDP data was available at a provincial level, but not available for the studied sub-regions in Nova Scotia. It was necessary to use an alternative version of sub-regional GDP in Nova Scotia which was calculated by multiplying the provincial GDP by the percent of the provincial workforce in the given sub-regions for the year of 2010. The main data source for Nova Scotia's provincial GDP was from Statistics Canada's Table 379-0030 (1998-2015). The Nova Scotia workforce data used for calculating the percentage of each region that contributed to provincial GDP was from Canadian Census' labor force population. The main source of data on local-currency GDP in Fujian, at both provincial and sub-regional levels, was the Fujian Statistical Yearbook (1998-2015). The official exchange rates for both provinces, which were used for converting the GDP from national currency to U.S. dollar, were obtained from the World Bank database (The World Bank, 2012).

Second, the ratios for national GDP at the official exchange rate and national GDP at PPP rate were calculated, and then the previously converted GDP at the official exchange rates was divided by this ratio to obtain the regional GDP at PPP rate, based on Equation 5.3 and 5.4). The data for national purchasing power parity (PPP), GDP and GDP at the official exchange rate in the two countries were also derived from World Bank database (The World Bank, 2012).

$$GDP_{ppp} = \frac{GDP_{OER}}{R_{er}} \quad \text{(Equation 5.3)}$$

Where: GDP_{ppp} represents the PPP GDP in the targeted region; GDP_{OER} represents the OER GDP in the targeted region; R_{er} represents the ratio for national OER GDP and national PPP GDP.

$R_{er} = \frac{GDP_{NOER}}{GDP_{NPPP}}$ (Equation 5.4)

Where: R_{er} represents the ratio for national OER GDP and national PPP GDP; GDP_{NOER} represents the national GDP at official exchange rates; GDP_{Nppp} represents the national GDP at PPP rates.

In addition, the temporal changes in PPP GDP per head in the two provinces from 1998 to 2015 were analyzed. The calculated GDP per head at PPP rate of 119 sub-regions in Fujian and 99 subdivided regions in Nova Scotia for the year of 2011 were all input into GIS, and raster files were then created for mapping the spatial changes of GDP per head.

5.2.1.3 Social Indicator - Human Health and Happiness

Human happiness refers to the degree to which an individual self-perceives the overall quality of his/her own life. Self-assessed health measures provide a subjective evaluation of overall population health. Self-rated health and happiness were selected as the key social indicators for agroecosystem health comparison between the two provinces. While described in detail below, in this study the self-reported health was defined as the percentages of people who reported being healthy or fairly healthy, while self-reported happiness included those self-identifying in categories of happy and neither happy nor unhappy.

The analysis of human health and happiness in Fujian and Nova Scotia was based on microdata collected from nationwide surveys in China and Canada. Data on human happiness and health in Fujian and Nova Scotia were derived from Chinese General Social Survey (CGSS) and Statistics Canada's Canadian Community Health Survey (CCHS), respectively (Canadian Community Health Survey, 2010; National Survey Research Center at Renmin University of China, 2010).

Perceived overall health in both CGSS and CCHS were measured by asking respondents to rate their health using a 5 or 10-point scale. The health data for both regions were re-coded, using a 3 points scales (3=excellent, good or very good, 2=fair, 1=poor or very poor). The variable of happiness was measured by asking respondents to rate their life satisfaction or living condition by using a hierarchical scale. Either a five or eleven-point scale was utilized in these measurements. The happiness data for both regions were coded, using a 3 point scales (3=very satisfied or satisfied, 2=neither satisfied nor dissatisfied, 1=dissatisfied or very dissatisfied). The percentages of people who reported being healthy (happy) or fair (neither happy nor unhappy) were calculated for 99 sub-regions in Nova Scotia and the province of Fujian.

Social-demographic variables for Fujian, including gender, age, marital status, education level, household registration status (rural or urban) and income level, along with the variables of self-reported health and happiness, were extracted from the CGSS survey data. Logistic regression was further conducted to determine if the odds of observing a response category of self-reported happiness in Fujian could be explained by the extracted social-demographic factors. Thus, the happiness measurements were selected as the dependent variable (1 = happy or neither happy nor unhappy, 0 = unhappy) and the socio-demographic factors were set as the independent variables. The human health predictor was coded as 1 = healthy or fair, 0 = unhappy; the gender predictor was coded as 1 = female and 0 = male; the age predictor was coded as 1 = older than 50 and 0 = younger than 50; the educational level predictor was coded as 1 = higher than secondary education and 0 = lower than secondary education; marital status predictor was coded as 1 = married, single or common-law relationship and 0 = separated and widowed; income level predictor was coded as 1= more than RMB 40, 000 and 0 = less than RMB 40,000; household registration status was coded as 1 = agricultural household registration status and 0 = non-agricultural registration status. The traditional 0.05 criterion of statistical significance was utilized for the tests. The Logistic regression model was established as follows.

$$\log(p(HA) = \log\left[\frac{p(HA)}{1-p(HA)}\right] = 1.760 + 1.636 * HE + 0.171 * HO \quad \text{(Equation 5.5)}$$

Then, p can be calculated by the following formula:

$$p = \frac{e^{1.760 + 1.636 * HE + .171\, HO}}{1+e^{1.760 + 1.636 * HE + .171\, HO}} \quad \text{(Equation 5.6)}$$

Where: *HA* represents the percentages in happy or neither happy nor unhappy category; *HE* represents the percentages in health or fair category; *HO* represents the percentages in household registration; p represents the probability that a case is in happy or neither happy nor unhappy category; e represents the base of natural logarithms (approx. 2.72).

Using the data of percentages of health categories (health categories of people older than 60 years old was derived from the 2010 China population census) and household registration status categories, the self-reported happiness for each sub-region was estimated, based on Equation 5.6.

Taking 2010 as the reference year, the percentages of people who reported being healthy (happy) or fair (neither happy nor unhappy) were calculated for each studied sub-region. The computed values were imported into GIS, and raster files were created to visually represent the spatial distribution of human health and happiness in the two provinces. At a provincial level, the temporal changes in self-rated health and happiness were studied, from 2003 to 2013 for the two study cases, in the two provinces.

5.2.2 Geospatial Analysis

The raster files of the selected indicators were generated for the two regions. The "Zonal Statistics as a Table" tool in GIS was employed to calculate the mean values of each zone for the three selected indicators (human happiness and health, soil erosion, and GDP per head). In the zonal statistic, 119 sub-regions in Fujian and 99 sub-regions in Nova Scotia were utilized as zones units. The mean values for these sub-regions were combined into one data set for the selected indicators; four outliers of Fujian sub-regions were removed from the data, resulting in a sample size of 99 for Nova Scotia and 115 for Fujian.

5.2.3 Generation of Agroecosystem Health Index

Since the selected indicators were expressed in different units, normalization was necessary before the indicators were aggregated into an *agroecosystem health index*. Among the indicators, indicators had a positive influence on agroecosystem health, whereas other indicators have a negative effect. To normalize the data, these indicators were calculated using Equation 5.7 and 5.8.

$$N_{ij}^{+} = \frac{I_{ij}^{+} - I_{min,i}^{+}}{I_{max,i}^{+} - I_{min,i}^{+}} \qquad \text{(Equation 5.7)}$$

$$N_{ij}^{-} = \frac{I_{max,i}^{-} - I_{ij}^{-}}{I_{max,i}^{-} - I_{min,i}^{-}} \quad \text{(Equation 5.8)}$$

Where N_{ij}^{+} is the normalized indicator i in subregion j that have a positive effect on agroecosystem health and N_{ij}^{-} is the normalized indicator i in subregion j that have a negative effect on agroecosystem health;

I_{ij}^{+} is the zonal statistical mean value of indicator i in subregion j that have a positive effect on agroecosystem health and I_{ij}^{+} is the zonal statistical mean value of indicator i in subregion j that have a negative effect on agroecosystem health;

$I^{+}_{max,i}$ and $I^{+}_{min,i}$ are the maximum and minimum values of indicator i that have a positive effect on agroecosystem health, $I^{-}_{max,i}$ and $I^{-}_{min,i}$ are the maximum and minimum values of indicator i that have a negative effect on agroecosystem health.

For example, the increased value of annual rates of soil erosion has a negative impact which means the higher the soil erosion rates, the less healthy an agroecosystem can be. On the other hand, increased GDP per head and human health and happiness are values with a positive correlation between the economic and social performance of the agroecosystem health. In such ways, the different kinds of indicators with different units of measurements were converted to a value ranging between 0 and 1, with higher values denoting better / healthier status.

To develop an index of agroecosystem health incorporating ecological, social and economic dimension, the annual soil erosion rates and GDP per head were directly taken into account, whereas the dimension of social performance was aggregated by averaging the normalized values of self-reported health and happiness. The aggregated health index of agroecosystem health for each sub-region was then generated by averaging the values of the three targeted dimensions of agroecosystem health (Parkins, 2007). The aggregated health index has a range from 0 to 1, with a higher value corresponding to the higher level of agroecosystem health.

5.2.4 Statistical Analysis

One-way analysis of variance (ANOVA) was conducted to determine whether there were significant differences between the mean values of the three indicators of agroecosystem health and the aggregated health index for Nova Scotia and Fujian. Means for each selected indicator and agroecosystem health index were calculated for each subregion in Nova Scotia and Fujian. Data analysis were conducted in SPSS. The differences were considered significant at $p < 0.05$ level.

5.3 Results and Discussion

5.3.1 Comparing Agroecosystem Health between Nova Scotia and Fujian

Nova Scotia and Fujian were compared with respect to selected indicators of agroecosystem health and the integrated agroecosystem health index, which were based on the zonal statistic results. Analysis of variance indicated significant differences between Nova Scotia and Fujian for all selected indicators as well as the agroecosystem health index. Means and the normalized values of the dependent variables are reported in Table 5.1.

The temporal changes in the selected indicators for the Nova Scotia and Fujian agroecosystems were analyzed as shown in Table 5.2 and Table 5.3. Overall, the estimated rates of soil erosion decreased slightly, whereas GDP per head and human happiness and health in Nova Scotia had trends upward over time. In contrast, there was an upward trend in GDP per head and human happiness in Fujian, but overall downward trends in the estimated soil erosion, as well as health for the periods, studied.

Table 5.1 Comparing agroecosystem health indicators across regions between Nova Scotia and Fujian

	Nova Scotia *n=99*	Fujian *n= 115*	F	P
Soil Erosion (t ha^{-1} yr^{-1})	0.82 (0.99)	124 (0.61)	447.83	< 0.001*
GDP per head (Int.l $)	410,19 (0.78)	11,475 (0.14)	1958.48	< 0.001*
Self-reported Health (%)	95 (0.87)	87 (0.44)	347.69	< 0.001*
Self-reported Happiness (%)	97 (0.87)	88 (0.18)	1882.44	< 0.001*
Health Index (dimensionless)	0.88	0.36	1825.54	< 0.001*

Note: The values in the brackets are the normalized values of the selected indicators, which are dimensionless, and range from 0 to 1.

The P value with “*” indicate that there is a significant difference between the two provinces for the associated indicators or index.

Table 5.2 Temporal changes of regional agroecosystem health indicators in Nova Scotia

Agroecosystem health measurement	Soil erosion ($t\ ha^{-1}\ yr^{-1}$) [1]	GDP per head (Int.l $) [2]	Human health/happiness (%) [3]
Annual average value	0.69 (2006)	21,243 (1998)	96.4/96.5 (2003)
	0.41 (2009)	33, 727 (2015)	97.1/97.2 (2013)
Mean	0.55	33, 765	96.6/96.8
Overall trend	Decreasing	Increasing	Both increasing with time

Note: 1 For soil erosion, data were available for 2006 & 2009. It is noted that this value is based on the average unit area value of soil erosion, which is slightly different from the mean values obtained from the zonal statistic.

2 For GDP/head, data was drawn from 1998 and 2015.

3 For human health and happiness, data was drawn for the year of 2003 to 2013.

Table 5.3 Temporal changes of regional agroecosystem health indicators in Fujian

Agroecosystem Health indicators	Soil erosion ($t\ ha^{-1}\ yr^{-1}$) [1]	GDP per head (Int.l $) [2]	Human health/happiness (%) [3]
Annual average value	135 (2006)	3,428 (1998)	93.7/90.0 (2005/2003)
	125 (2009)	19,551 (2015)	83.2/93.2 (2013)
Mean	130	23409	84.7/89.4
Overall trend	Decreasing	Increasing	Decreasing/Increasing

Note: 1 For Soil erosion, data was available for 2006 & 2009.

2 For GDP/head, data was drawn from 1998 and 2015.

3 For human health and happiness, data was drawn for the year of 2003 to 2013.

5.3.1.1 Soil Erosion

The result of ANOVA analysis shows that Fujian had a significantly higher level of soil erosion, compared with Nova Scotia. The zonal statistical results indicated that the estimated rate of soil erosion ranged from 7 $t\ ha^{-1}\ yr^{-1}$ to 320 $t\ ha^{-1}\ yr^{-1}$, with a mean value at 125 $t\ ha^{-1}\ yr^{-1}$, as of 2009 as the reference year (Table 5.1). In contrast, Nova Scotia had a soil erosion rate that ranged from 0.09 to 17 $t\ ha^{-1}\ yr^{-1}$, with an average value at 0.82 $t\ ha^{-1}\ yr^{-1}$. As well, the temporal analysis revealed that the mean annual estimated rate of soil erosion in Nova Scotia, predicted by the RUSLE model, had a downward trend in the time interval examined in this study (Table 5.2). The mean of the estimated rate of soil erosion in Fujian had a downward trend during the period 2006 to 2009 (Table 5.3).

Although there is no field study available for comparing soil erosion between Nova Scotia and Fujian, the values of estimated RUSLE factors and soil erosion rates were compared with the studies carried out in areas having similar geo-environmental and rainfall characteristics. The range of the estimates in the two regions were found to be within the ranges found in these studies as presented in Table B8 in Appendix B (Millward & Mersey, 1999; Kouli *et al*., 2009; Wall *et al*., 2002, Huang *et al*., 2013; Jiang *et al*., 2015; Napoli *et al*., 2016). Accordingly, the most vulnerable type of land use for soil erosion was bare land, urban area, and agricultural land and the least vulnerable one was the forested areas; changing forest into agriculture lands can greatly speed and increase soil losses (Lech-hab *et al*., 2015). This can explain why Fujian has a higher average annual rate of soil erosion, in comparison with Nova Scotia, since Fujian has a larger agricultural area and a smaller area under forest. Also, supporting this are reports by Liu & Diamond (2005) that China, as the world's most populous country, has faced greater environmental challenges than other major countries. According to Wang *et al*., (2012), China has been experiencing rapid economic development and urbanization, which has resulted in massive infrastructure construction. This infrastructure construction has a major influence on landforms, vegetation, and waterways; and has led to land degradation and soil erosion. Fujian is one of the most rapidly developing regions, with a large population (38.39 million). Ananda & Herath (2003) agree and further comment that this expanded cultivation and urban land use has been an accelerator for soil erosion. In addition, there is a lack of both scientific information and regulations to control soil erosion, which has partially contributed to the present situation pertaining to soil erosion in China.

In contrast, Nova Scotia only had 3% of the areas devoted to agricultural land use, and the Environmental Farm Plan conducted in Nova Scotia has the potential to encourage and educate for best management practices and workable solutions to reduce or prevent the potential environmental risk (Yiridoe *et al*., 2010). This would have reduced the negative effects of agricultural activities that human beings may bring to nature.

The result also indicates that during the two study periods, the estimated rate of soil erosion had downward trends in both Nova Scotia and Fujian. Although there is no information available for the changes in soil erosion in Nova Scotia, the downward trend of soil erosion in Fujian over time is similar to the finding reported by Lin (2004). Fujian had a 3.1% decrease in its R (rainfall erosivity) factor, which contributed to a reduction in the estimated rate of soil erosion in Fujian, even though the C (cover management) factor and P (support practices) factor increased by 2.6% and 1.1%, respectively. It can be concluded that the R (rainfall erosivity) factor had a significant effect on the estimated rate of soil erosion in Fujian; however, C (cover management) and P factors were the most critical factors in reducing the estimated soil erosion rates in Nova Scotia. This data indicates a need to implement suitable soil conservation practices in Fujian province. Forest and grasses are better at controlling soil erosion than other land uses, thus, planting forests and grasses will significantly reduce the overall soil erosion rates in the entire watershed. It may be advisable to more fully use strip and terracing cropping to reduce the soil erosion while maintaining the crop yields.

Slope length and slope steepness (LS) factor and soil erodibility (K) factors remained unchanged during the data comparison period of this study. Based on analysis of the change of the other factors, the R (rainfall erosivity) factor in Nova Scotia rose by 7.6% between the study periods, but the decline in C (cover management) factor (30.6%) and a slight decrease in P (support practices) factor (0.2 %) resulted in the sharp decline in the estimated erosion rate in Nova Scotia for the two periods. However, the decline in soil erosion in Nova Scotia is attributable to the difference in water bodies and the increase of agricultural land use. Since the land use map was derived from satellite imagery, the water areas are obviously responsive to local weather and climatic events close to the time the images were taken. Therefore, considerable caution should be applied in including the increase of water bodies area in the soil erosion estimation.

5.3.1.2 GDP per head

The comparative analysis of the results shows that Fujian (mean: Int.l $ 11,475) has a significantly lower GDP per head, compared with Nova Scotia (mean: Int.l $ 41,019) (Table 5.1). The zonal statistical results suggest that regional GDP per head in Nova Scotia ranged from Int.l $ 20,359 to Int.l $ 51,160 in 2010. In contrast, Fujian had regional GDP per head that ranged from Int.l $ 4791 to Int.l $ 20,666 reported for 2010. There is no study to report the cross-national differences on GDP per head between Nova Scotia and Fujian. However, there are a few separate studies on either Fujian or Nova Scotia's GDP that could provide evidence for the estimated GDP per head in the two regions. It is not surprising that Nova Scotia, as part of a developed county, has a higher level of GDP per head or income level, compared with Fujian that is from a developing country. MacArthur (2014) has pointed out that the Canadian economy is uniquely dependent on its natural resource exploration. With a relatively small population, Canada has the largest land masses and quantities of natural resources, which have granted Canada an advantage in wealth generation, compared with other countries (Hessing & Summerville, 2014). In contrast, China is still in the formative stage of its modernization and economic development. With a large population, although the growth rates of economic development are fast, the GDP per head is still relatively low compared with other less populous nations. In addition, the limited natural resources and increasing environmental problems limit the capacity of economic development in China.

Upward trends were observed for GDP per head in both Nova Scotia and Fujian over the years (Table 5.2 and 5.3). The estimated uptrend of GDP was consistent with Feng's (2014) findings that the GDP in Fujian had a continuous increase in recent decades. Feng (2007) noted that the services and industry sectors contributed most to the growth of GDP in Fujian. The agriculture sector accounted for 17.2% of the total GDP, while the industry and service sectors constituted 46.0% and 36.8% respectively, of the total GDP in 1998. The agriculture sector was down to 8.3% in 2015, while the industry and services sector was up to 52.0% and 39.6%, respectively. It is obvious that the roles and relative importance of the agriculture and services sectors were switched during the period from 1998 to 2015. This exchange and the steady development of the industry sector resulted in a stronger economic structure for Fujian Province over time that increased its total amount of GDP.

The estimated GDP in Nova Scotia increased during this study period. The similar findings of Nova Scotia GDP could be seen in Sharpe & de Avillez (2012)'s research. The fluctuation of GDP in Nova Scotia can be explained by some very different factors, including improvements in technology and organization and capacity utilization (Sharpe

& de Avillez, 2012). This is combined with the changes of capital input and labor resources to explain the changing trend of economic development in Nova Scotia. Looking at the economic structure of Nova Scotia in 1998, goods-producing industries accounted for 22.4% of the total GDP per head, while services-producing industries contributed 76.3 %. Agriculture accounted for only 2.1% of the provincial GDP. By 2011, the goods-producing industries decreased to 19.5% and the services-producing industry increased to 80.4%, while the agricultural sector contributed less than 3% of the total GDP. Therefore, the economic structure of Nova Scotia was increasingly based on service-producing industries. The GDP in Nova Scotia was especially sensitive to the changes in labor resources. Over the last decade, the total number of employed workers in Nova Scotia grew from 1998 to 2012, except for a temporary decline in 2009. Since 2012, when the total labor force peaked, there has been a continuous downward trend for GDP per head in Nova Scotia. This trend is similar to the overall pattern of total GDP in Nova Scotia.

5.3.1.3 Human Health and Happiness

The ANOVA analysis shows that Fujian had significantly higher levels of self-reported human health and happiness, compared with Nova Scotia (Table 5.1). The zonal statistical results suggest that the percentages of people that self-reported as being fair or healthy among the subregions in Fujian averaged 87 % with a range from 79 % to 93% in 2010. In contrast, Nova Scotia had 95 % of the population who reported a fair or healthy status and this percentage ranged from 94 % to 95%. The population that reported as neither happy nor unhappy, or happy among the sub-regions in Fujian was averaged at 88 % with a range from 85 % to 94%, while this percentage ranged from 95% to 99% with an average value at 97% in Nova Scotia in the year of 2010. Overall, over the 10-year span, Nova Scotians reported an increased self-assessment of their health, while an obvious upward trend was observed for human happiness in Nova Scotia (Table 5.2). Results indicate that, in Fujian, there was still an overall upward trend in human happiness the decade studied (Table 5.3). In contrast, a downward trend was observed for the group reporting as being in a fair or good health status.

The results of this study reveal that the Nova Scotia respondents self-scored higher in happiness and health measures, compared with Fujian respondents. This is consistent with studies that have shown that Canada has ranked within the top ten happiest nations, while China had a relatively lower rank, for human self-reported happiness (Helliwell *et al*., 2015). The findings of the Gallup World Poll suggested that Canada is one of the top ten countries with respect to happiness. With China's economy and society changing quickly, it would seem likely that how people perceive their life and self-health in its culture would be different from that in Canada. This is probably due to China's faster rate of economic modernization, urbanization and personal economic status. The Chinese economy has recently maintained economic growth at remarkable rates averaging at 8%. However, the growth rate has been accompanied by serious environmental and social problems, including pollution and food insecurity, shortages of resources and energy, growing economic inequality, property price booms and unemployment.

Therefore, the Chinese population has faced rising changes and challenges, which can cause stress and health problems. Moreover, Chinese society is still predominately a highly collectivist culture. People are more likely to act in the interests of the group and not necessarily of themselves (Earley, 1989; Spector *et al*., 2004). Chinese people are expected to work hard without putting much emphasis on leisure time and are likely to be encouraged to control the gratification of their desires (Hsu & Huang, 2016). The disparities in education, medical, and public facilities between rural and urban areas appear to be associated with a large number of unhappy and unhealthy people in rural areas in China. On the other hand, Canada, has high values of factors of income level, healthy life expectancy, having someone to trust, generosity, freedom and a well-established public social welfare system with robust social ties (communities) (Helliwell *et al*., 2017). This can be explained by the relatively more extensive social support system in Canada. Provinces in Canada provide publicly funded healthcare, elementary or secondary school education, with some of the costs partially subsidized by the federal government and a small percentage of the costs under private sectors. Therefore, as Armitage (2003) reported, members of the society could access free medical health care. It is noted that seniors can access old age pension, and low-income individuals and families can access social assistance and support. There are also different social organizations providing social services designed to support children, youth, the elderly, and the physically disabled individuals.

Also, the results suggest that Nova Scotians have become happier and healthier over time, while Fujian has become happier but less healthy. Sharpe & Capeluck (2012) indicated that Canadians were happy and become happier over time, while Nova Scotia ranked as one of the highest average levels of life satisfaction in Canada based on the 2003-2011 period average. That self-reported happiness had an upward trend, while the self-reported health had a reversed trend in Fujian was unexpected. Brockmann *et al*., (2009) also noted that China experienced a massive improvement in living standards and yet people's subjective well-being fell significantly over the decade, which is different is from the results that we found. This has suggested both negative and positive sides of GDP account. Rapid economic modernization and urbanization in China have caused serious environmental issues, including pollution and food security, shortages of resources and energy which was associated with increased health issues.

5.3.1.4 Agroecosystem Health Index

The results from ANOVA analysis shows that Fujian had a significantly higher agroecosystem health index, compared with Nova Scotia. Recall that the normalized values of all selected indicators in Fujian were found to be significantly lower than the corresponding indicators in Nova Scotia. It is therefore not surprising that this is also true when the combined agroecosystem health index was compared between the two regions. Since the GDP per head, and human happiness and health were regarded as positive indicators, while soil erosion was regarded as a negative indicator, the results confirmed that Fujian had a higher level of soil erosion, but lower values in GDP per head, human health and happiness.

5.3.2 Spatial Distribution of Agroecosystem Health

The performance of agroecosystem health for each subregion in Nova Scotia and Fujian was studied according to key indicators selected. The spatial distribution of the selected indicators (normalized) and the final aggregated index of agroecosystem health for Nova Scotia and Fujian are shown in Figure 5.1 and Figure 5.2. All the normalized values are ranged from 0 to 1, with higher values representing healthier performance.

5.3.2.1 Spatial distribution of agroecosystem health in Nova Scotia

The results show a cluster of low values (denoting higher level of soil erosion) in the northeast coastal area of Nova Scotia increasing towards the southwest. This spatial pattern of soil erosion in Nova Scotia could be explained by the low values of soil erodibility factor (K) and LS clustered in the northern Nova Scotia. In addition, the northern coastal area in Nova Scotia has a relatively higher proportion of agricultural land, which increases the vulnerability of soil to erosion. The regional GDP per head exhibited a cluster of higher values in the central region of Nova Scotia, especially the provincial capital area of Halifax. In addition, the dwellers in Halifax, Kings, and Annapolis counties, that are mainly from the central and western region of Nova Scotia, have higher values of self-reported happiness and health. This suggested that central Nova Scotia, especially Halifax had advantages, over other regions in Nova Scotia in terms of public facilities, personal safety and security, sense of community, social support, lower corruption, generosity, and freedom to make life choices. Halifax has the average youngest population among the counties in the province, which probably explains the higher level of economic development and the relatively healthy population of this section of the province (Nova Scotia Department of Seniors, 2009).

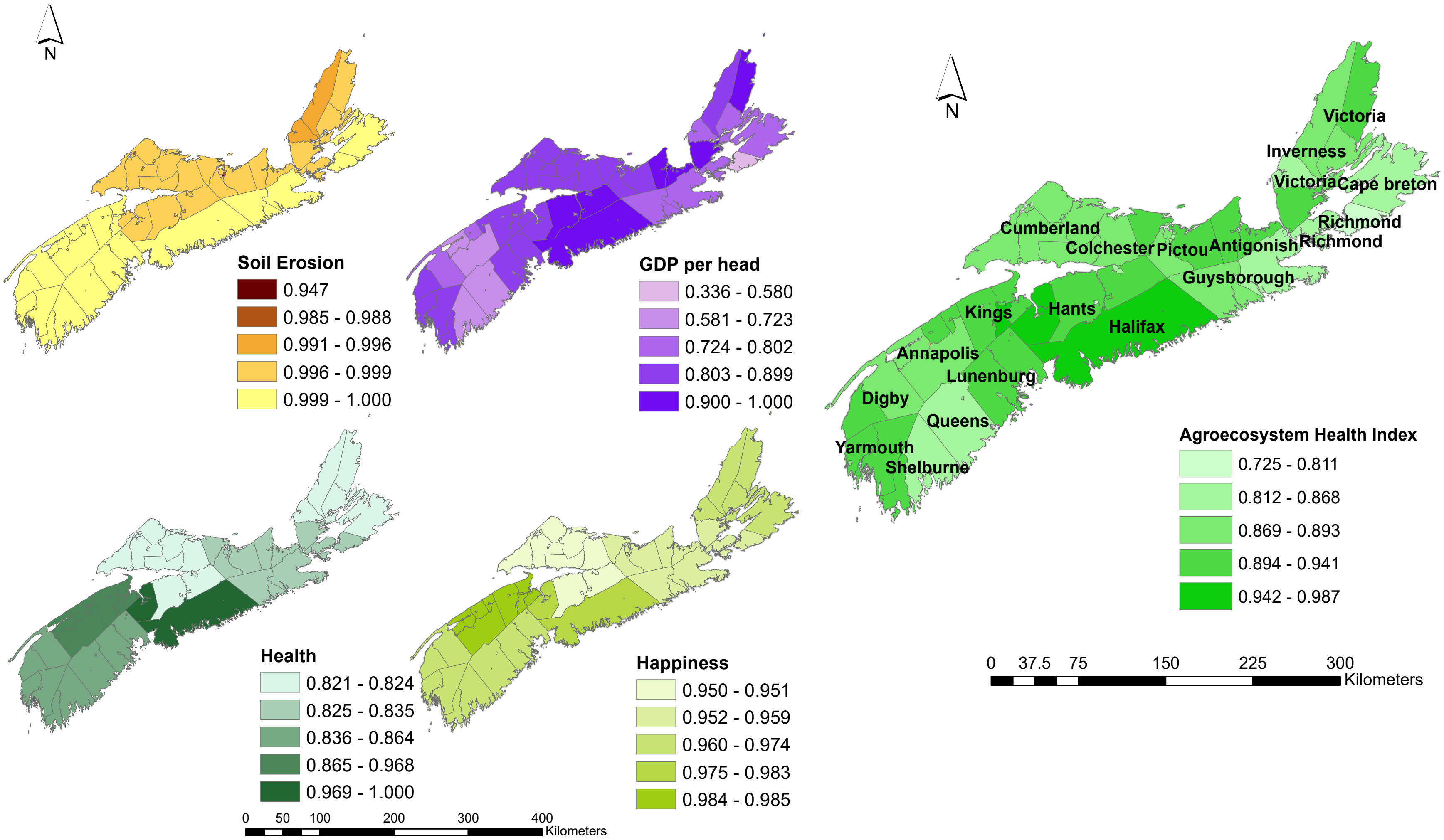

Figure 5.1 Agroecosystem health indicators and agroecosystem health in Nova Scotia (normalized)

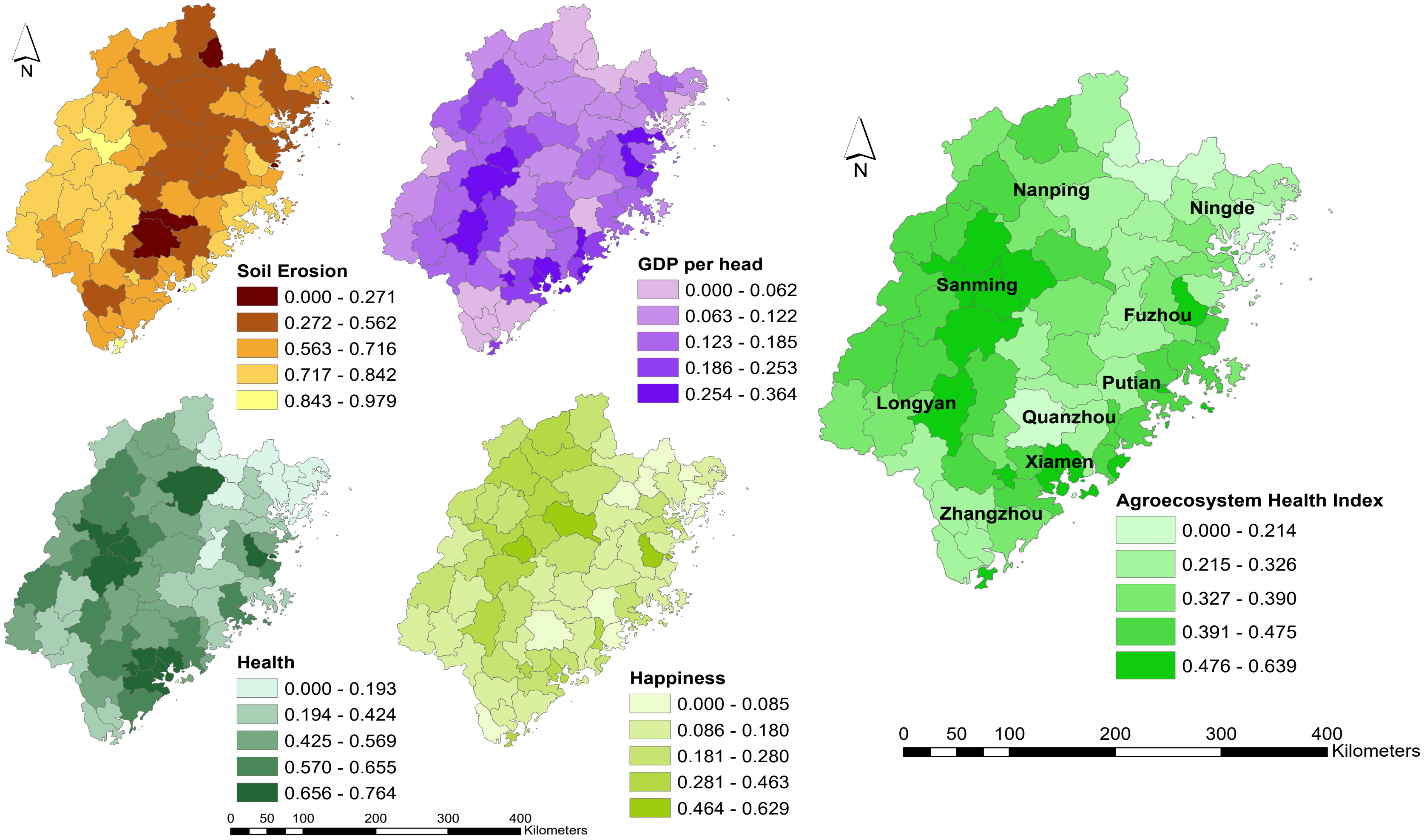

Figure 5.2 Agroecosystem health indicators and agroecosystem health in Fujian (normalized)

Figure 5.1 presents the spatial variation of integrated agroecosystem health index in Nova Scotia. It is observed that high values are clustered in the central region of Nova Scotia, especially for Halifax, mostly parts of Kings and the western part of Hants counties. These regions had a relatively higher GDP per head, and a higher level of self-reported human happiness and health, suggesting relatively superior socioeconomic conditions, compared with other regions. Moreover, lower estimated rates of soil erosion contribute to a better bio-physical performance in those regions. In contrast, the low values of agroecosystem health index were concentrated in the northeast part of Nova Scotia. These regions had either a higher level of soil erosion and a lower self-perceived happiness and health.

5.3.2.2 Spatial distribution of agroecosystem health in Fujian

The spatial analysis of soil erosion suggested that the mainland of eastern coastal areas had lower values, compared with the inland region in the northwest. This suggested a higher level of soil erosion in eastern coastal areas in Fujian which is consistent with the findings reported by Chen *et al*., (2006). The GDP per head in Fujian were found to be higher in the coastal area, especially in southeast coastal areas where a larger proportion of the urban area is located. Whereas the low-values clustered in the northern inland co-exist with where the predominant rural area is located (Chen, 2006; Zhan *et al*., 2016). Also, the spatial pattern of self-reported human happiness and health displayed a similar spatial pattern as that shown by the regional GDP per head.

As showed in Figure 5.2, high values clustered around Sanming (northern inland), Longyan (southwest inland) and some part of southeast coastal areas, while the cluster of low values for agroecosystem health was found in Ningde (northeast coastal area). It is not surprising that Ningde was the least healthy area in Fujian, as it had relatively higher soil erosion, but lower GDP per head, as well as the smaller proportion of happy and healthy people. In contrast, Saming was the area associated with healthy inhabitants, followed by Longyan. Even they were not the regions with the best economic performance; they have comparatively lower soil erosion and a higher level of human happiness and health.

Consistent with Vadrevu at al., (2008), the pattern of the agroecosystem health index is complex and results from the combination of ecological, social and economic components. These components influence the index of agroecosystem health in a complex and coupled way (Su *et al*., 2012). The coupled effect varies in a different region or at different study scales. As Su *et al*., (2012) indicated that two regions presented similar values of agroecosystem health index may be quite dissimilar with respect to its contributing factors.

5.4 Conclusion

This chapter presents a comparison of agroecosystem health between Fujian and Nova Scotia, combining ecological, economic, and social components. This study developed a methodological approach using multiple criteria analysis for agroecosystem assessment at a provincial scale in a global context. Also, the integration of agroecosystem health that conserves both ecological and socioeconomic components developed in this study can be applied to any agroecosystem at a larger regional scale.

This study has generated a methodological approach using multiple criteria analysis based on GIS to demonstrate how to conduct interdisciplinary research for agroecosystem assessment. The application of GIS in multi-criteria assessment which incorporates remote sensing data and census data has provided a novel approach and technique in this area. The spatial distribution of multi-criteria provide an evaluation of sustainable performances of the two agroecosystems under different conditions. The results obtained from the empirical study in the two provinces attests to this. For instance, the GIS-based analysis of the spatial difference in agroecosystem health indicators and the final integrated agroecosystem health can be valuable in identifying the strengths and opportunities of each sub-region. This information for Fujian and Nova Scotia can be useful for policy decision makers to prioritize different regions with the most appropriate regional policies to enhance agroecosystem health.

Assessing agroecosystem health involves a considerable data set of multiple dimensions, given the complex structural organization and functions of agroecosystems (Su *et al*. 2012). It is challenging to aggregate the multi-dimensional data into one integrated index of agroecosystem health because the data are measured and documented at different scales and in different units (Vadrevu *et al*. 2008). This study has overcome this challenge by normalizing the data and using the averages of the values of all selected indicators. Also, the utilization of GIS in the multi-dimensional evaluation of agroecosystem makes it easy to obtain a more accurate aggregated agroecosystem health integrity, compared with traditional approaches.

The aggregated health index can give an integrated assessment of agroecosystem health by bringing together health criteria from ecological, social, economic and environmental. The visual presentation of multiple dimensions of agroecosystem health and the aggregation of multiple indicators into one index makes it easier to understand such a complex concept, and monitor the spatial variations of each indicator and contribute to the agroecosystem health index. This study not only provide information of the variation in agroecosystem health in time and space-time, but it can also identify the sub-regions where initiatives need to be taken, policy decisions need to be made or changed to improve regional health and sustainability. This, therefore, potentially could be utilized as a decision support tool for monitoring and assessing regional management strategies and decision options.

This study proposed a uniform assessment that makes it possible to compared cross-regional agroecosystem assessment. This research has provided a practical example of how cross-nations agroecosystems could be assessed and compared. It has the potential to contribute to the literature in cross-cultural research with regards to ecosystem assessment, as well as providing information about ecological, economic, and social performance in time and space that could be useful to public decision-makers in the two study areas.

Some methodological limitations, however, should be addressed and overcome in this study. The geo-statistics utilized for obtaining the mean values of each indicator may vary by using input zones at different scales. One of the limitations of this study is the lack of direct data on agroecosystem health at local and regional scales. In addition, low spatial resolution, lack of categorical precision, and low classification accuracy for many cover types have limited the evaluation precision. The study has utilized a series of secondary data from different countries, and the measurements of the targeted indicators might be based on different contexts. The process of reinterpretations of the variables might have introduced some errors. Therefore, uniform approaches and measurements with a distinctive design for this research area could be one of the further studies.

The complexity of agroecosystem required an integrative assessment that can improve the understanding of agroecosystems and long-term sustainability of agroecosystem with consideration various components. It would be ideal to use multiple indicators from each discipline. Multidimensional assessments, however, can be challenging and expensive to be implemented at a regional scale because of the unavailability of primary data. Therefore, it is impossible to include all aspects of indicators into one single research. That is why only one indicator for each discipline was utilized as a starting in building a good model for evaluating agroecosystem health. One of the major drawbacks, therefore, is that the selection of agroecosystem health indicators may vary in different social-ecological contexts, and at different scales. The aggregated agroecosystem health index is very sensitive to the selected key indicators, and may vary greatly if different weights were assigned to the key indicators. Therefore, further studies are suggested to include more indicators for agroecosystem health evaluation, and the weights can be considered when the aggregated index is generated.

As well, the selected health indicators and the integrated health index also vary at different scales. There is a need to simultaneously investigate different aspects of agroecosystem health at different scales (Xu and Mage, 2001) so that the nature of agroecosystem health can be to provide a better understanding of agroecosystem health. The assessment of agroecosystem health can also be extended to more regions, countries at different scales. An interesting further study, then, would be to obtain a full ranking of the regions/countries according to their agroecosystem health and further investigate the impact of various decision makings in different on agroecosystem health.

CHAPTER 6 CONCLUSION

6.1 Introduction

There is growing consensus that agroecosystem health, suggested as a framework for the assessment of agroecosystem, would be a constructive approach to guide agricultural management strategies and agricultural research (Okey, 1996; Xu & Merge, 2001; Vadrevu *et al*., 2008; Peterson *et al*., 2017). Despite recent research in agroecosystem health, there continues to be a lack of scientific basis for an integrated (ecological-social-economic) assessment of agroecosystems on a larger scale in a global context (Xu & Merge, 2001). This study has presented an empirical exploration that incorporated a multi-disciplinary approach to assess agroecosystem health by combining ecological, social and economic components. The major differences in agroecosystem health between the two study areas and the reasons for those differences are analyzed in this dissertation.

In this chapter, the main findings in relation to the research questions and objectives are summarized. In addition, the limitations and implications of this study are presented, and recommendations for further research are suggested.

6.2 Findings with regard to the Research Questions

The goal of this research was to establish an integrated (ecological-social-economic) framework for agroecosystem health evaluation on a larger scale within a global context. To achieve this goal, it is necessary to answer some prerequisite research questions.

Re: Question 1: How can agroecosystem health be measured, combining ecological-social-economic components?

Agroecosystems are complex functional units which are composed of diverse components (Belcher, 1999). The health of the agroecosystem, therefore, draws a broad perspective which integrates ecological, social and economic components, which should be taken as the basis for agroecosystem assessment. To gain a better understanding of the theoretical basis of this research, a literature review was conducted to address research on the concepts of agroecosystem health and to elaborate on how agroecosystem health interacts with agroecosystem management. Chapter 2 lays out the theoretical development of this thesis, exploring the concepts of, and what constitutes, agroecosystem health, and how the assessment of agroecosystem health could help inform agroecosystem management. It has provided a theoretical basis for developing techniques and approaches that are needed for enhanced agroecosystem assessment and management. A background discussion on existing problems in research on agroecosystem health was presented, and the review concluded that the understanding of agroecosystem health provides the scientific basis for informing sustainable agroecosystem management, while reasoned, informed agroecosystem management is the pathway to maintaining agroecosystem health. A conceptual model for sustainable agroecosystem management, from the farm scale, to watershed, to a provincial/regional scale, was also proposed in this review.

After addressing the theoretical basis of agroecosystem health and management, Chapter 3 has furthered understanding of agroecosystem health from a multidimensional perspective on a larger scale within a global context. The complexity of the agroecosystem emphasizes a need for integrative assessment methods that establish long-term sustainability of agroecosystems with consideration of the various components (Gliessman, 1990; Ananda & Herath, 2003). In order to develop frameworks for evaluating the performance of agroecosystem, experts from social, economic and ecological sciences, both in Canada and China were invited to participate in a survey. The statistical analysis of the survey data has shown that the perceptions of Canadian experts exhibited significant differences on key criteria to gauge agroecosystem health, in comparison with Chinese experts. Fewer than half of the selected indicators were jointly suggested by experts from both countries, especially for social and economic indicators. In addition, the rankings of the indicators were significantly dissimilar between the two nationality groups. The Hypothesis 1, therefore, has been confirmed that there are significant differences in the perceptions towards agroecosystem health indicators between Canadian and Chinese experts. However, the study did identify key indicators supported jointly by both Canadian and Chinese experts; these were soil organic matter, soil erosion and contamination, air quality, water quality, biodiversity, land cover diversity or coverage, extension and availability of social services, happiness and health of the population, Gini index (fairness and equality), GDP per capita, farm stability and resilience as well as energy and resource efficiency. Soil erosion, GDP, and human happiness/health, were the common primary indicators for agroecosystem health identified from the perspectives of ecology, economics and social science used in the case studies that followed.

The empirical studies presented in Chapter 4 detailed how agroecosystem health can be measured using multi-criteria based on a GIS environment. Using two case studies of Nova Scotia and Fujian (Canada and China), Chapter 4 has demonstrated the usefulness of GIS as a tool in monitoring the ecological, social and economic components of agroecosystem health. The spatial changes in the identified key indicators within the case study regions were explored and visually presented, using GIS. Case studies were focused on the political unit of provinces but also included a detailed examination of the indicators within sub-regions of the primary case study provinces. The results of this study suggested that it is feasible to use GIS as an effective tool to combine remote sensing and census data in agroecosystem assessment across scales, which has confirmed Hypothesis 2. The case study findings revealed that the three components of agroecosystem health exhibited differences among different sub-regions.

Chapter 5 has further demonstrated the application of the established framework to conduct a comparison of agroecosystem health between Nova Scotia and Fujian, at a provincial scale. The three previously identified indicators, representing different dimensions of agroecosystem health, were applied through an in-depth comparative study on agroecosystem health between Nova Scotia and Fujian. The empirical comparison between the two case studies suggests that the developed model of agroecosystem health assessment can be applied in a global context as well as regionally.

Re: Question 2: Are there significant differences in the level of agroecosystem health between Nova Scotia and Fujian provinces?

Since agroecosystem components vary over time and geographical dimensions, and certainly are socially diverse among various national contexts, the health of agroecosystems also varies geographically and over time. The provinces of Fujian and Nova Scotia are two case studies that differ substantially in terms of economic and social and cultural characteristics; however, similarities exist in geographic conditions such as coverage of forest and biodiversity.

This dissertation presents an empirical comparison of agroecosystem health between Nova Scotia and Fujian. The two provincial study areas were compared concerning the identified key indicators of agroecosystem health and the final aggregated agroecosystem health index, which were based on the zonal statistic results. Analysis of variance indicated significant differences between Nova Scotia and Fujian for all selected indicators as well as the agroecosystem health index.

The findings presented in Chapter 5 indicated that the estimated rate of soil erosion for Fujian had a mean value at 125 t ha^{-1} yr^{-1}, while Nova Scotia had a soil erosion rate averaged at 0.82 t ha^{-1} yr^{-1}, as of 2009 as the reference year. In addition, the estimated rate of soil erosion had a downward trend in both Nova Scotia and Fujian, during the study period. Results indicated that Fujian (mean: Int.l $ 11,475) has a significantly lower GDP per head, compared with Nova Scotia (mean: Int.l $ 41,019). Upward trends were observed for GDP per head in both Nova Scotia and Fujian over the years.

The zonal statistical results suggest that the percentages of people that self-reported as being fair or healthy among the subregions averaged 87 % in Fujian, whereas Nova Scotia averaged 95 % of that percentage. The population that reported as neither happy nor unhappy, or happy among the sub-regions in Fujian was averaged at 88 %, while this percentage is 97% in Nova Scotia in the year of 2010. Overall, over the 10-year span, an obvious upward trend was observed for both human health and human happiness in Nova Scotia (Table 5.2). Results suggested an overall upward trend for human happiness, but a downward trend for human health in Fujian.

The results are therefore not surprising that Nova Scotia had a significantly higher level of agroecosystem health, in comparison with Fujian, using aggregated agroecosystem health index, combining identified key indicators. Hypothesis 3, therefore, has been confirmed here.

To achieve a healthy and sustainable system at multiple spatial scales from the farm, to the watershed, to the global scale, there is a need for more systematic and holistic approaches to both understanding and managing agroecosystems (Costanza, 1995). Overall, Chapter 2 described bases for theoretical framework and approaches to understanding and managing agroecosystems; this provides a basis for developing techniques and approaches to multidimensional evaluation of agroecosystem that is needed for enhanced agroecosystem management and policymaking. Chapter 3 has established a framework of agroecosystem health, with various indicators identified and ranked by Chinese and Canadian experts. Using two case studies, Chapter 4 and 5 has explored the usefulness of GIS in monitoring the ecological, social, economic components of agroecosystem health. The normalized data of the key indicators were further integrated to generate the final agroecosystem health index for contrasts of overall health, as well as selected key indicators, between the two regions.

6.3 Novel Contributions to Science and Implications

This dissertation contributes to the theoretical and methodological bases for providing a methodological approach using multiple criteria analysis based on GIS to demonstrate how to conduct multidisciplinary research for agroecosystem assessment at a larger scale, and within a global context.

6.3.1 Theoretical Contributions

Societal values, perceptions and attitudes towards agroecosystem health directly affect environmental education and policymaking, which are vital to the environmental protection and agroecosystem management (Tuan, 1990; Kollmuss & Agyeman, 2002; Dietz & Shwom, 2005; Kohler, 2014). However, few studies have addressed national and cultural differences in perceptions and knowledge in regard to agroecosystem health. This study has firstly provided a comparative study on perceptions towards agroecosystem health between Canadian and Chinese experts (Chapter 3). This study has documented differences and similarities in the perceptions of agroecosystem health among three academic specialty groups (ecologists, sociologists and economists) from both China and Canada. This provides evidence of the global environmental attitudes associated with and influenced by societal and cultural context. In addition, it has also developed a knowledge of international comparison on economic, social and economic performance within an intercultural context.

One of the most innovative features of this study is the exploration of spatial changes in ecological, social and economic components of agroecosystem health. The studied spatial pattern of agroecosystem health components, utilizing key indicators, has provided new insight on how agroecosystem health varied spatially for the ecological, economic and social aspects. In the literature, however, the biophysical and social-economic components have rarely been measured and compared within a global context. My research has firstly examined how developed and developing countries differ in how ecological and social-economic components perform. In addition, the suggested spatial changes in the measured indicators contribute to system theory through advancing a better understanding of the complexity of agroecosystems, which serves as the analytical basis of agroecosystem health assessments. These were probably obvious to the experienced farmer or rural inhabitant but now show the scientific, objective evidence from census, and GIS spatial databases are the much-needed foundation for evidence-based, scientifically-founded recommendations and policies.

A significant theoretical contribution of this research is stimulation of a platform for dialogue among ecologists, sociologists and economists, in an intercultural context. Experts from the academic fields of ecology, economics and social science were invited to identify agroecosystem health indicators in the first round of the survey, and in the second round were requested to rank the previously identified indicators. The survey is developed as a consultation process, but the information shared by the experts had also been passed back to the survey respondents during the surveys conducted. This study, therefore, played a role in facilitating dialogue among experts from the three disciplines through sharing their knowledge, experiences and the values. Overall, this research points to the importance of a joint effort by ecologists, sociologists and economists to use agroecosystem health to realize the sustainability of agroecosystems. This is an opportunity for further refinement and identifying differences between agricultural sub-disciplines and even the terms and concepts and definitions between both sub-disciplines and then in translation.

6.3.2 Methodological Contributions

One important novel methodological contribution of this study is the establishment of a framework for agroecosystem health assessment that integrated ecological, social and economic components, that can be used at a regional scale. The evaluation of agroecosystem health at a regional is a meaningful, timely task for both science and social practice. However, there is a lack of scientific basis for an integrated (ecological-social-economic) assessment of agroecosystems on a larger scale and in a global context. In this study, I not only developed an integrated framework for agroecosystem health assessment combining ecological, economic and social components, but also used Nova Scotia and Fujian provinces as contrasting geographic and political regions to apply the framework and evaluate both spatial and temporal changes of agroecosystem health.

The proposed framework in this reseach is based on an integration of participatory approaches and systems theories. To address the multiple goals of agroecosystem, it is of importance to hear the voices of multidisciplinary groups of specialists and scientists who understand the need for the balanced between the social-economic development and environmental protection. This framework of agroecosystem health presented here is underpinned by knowledge and experience shared by experts from social, economic and ecological sciences, both in Canada and China. The framework not only provides a list of indicators of agroecosystem health, but also informs the priorities of the identified indicators. This serves as the basis for negotiation and consensus building in identifying crucial components of an index, as well as a guide to evaluation and management of agroecosystems (Gitau *et al*., 2008). The study interpreted the process of the development of the set of agroecosystem indicators, shedding new light on the role of participatory approaches in agroecosystem health evaluation.

Another significant methodological contribution is the special utilization of using GIS in agroecosystem health that combines remote sensing data and census data. GIS can be an invaluable tool in the multi-criteria assessment of agroecosystems. Integrating remote sensing data and census data in a GIS environment, in this study agroecosystem health was evaluated and analyzed, geographically, at both sub-regional and provincial scale in a global context. This study has highlighted the important role of GIS maps in demonstrating the biophysical and social-economic conditions of agroecosystem health across the case study area visually, and in exploring the interplays among these components. The GIS-based multiple criteria analysis based on economic, social and ecological indicators developed, is able to highlight the sub-regions in the two study areas which need extra support and assistance with for their agroecosystem sustainability. The spatial analysis of agroecosystem health can also help policymakers to identify the strengths and weaknesses of regions with the most appropriate regional policies that can enhance agroecosystem sustainability.

A third novel contribution to methodologies for this research is the presentation of an empirical intercultural comparison of agroecosystem health at a regional scale. This study, to my knowledge, is an initial intercultural research and comparison analysis on agroecosystem health. This study proposed a uniform assessment that makes it possible to compared cross-regional agroecosystem assessment. The study refined soil erosion assessment by combining data sources that can be accessed any place in the world, while PPP was utilized to improve the international comparability for GDP per head. The measurements of self-reported human happiness and health, for both provinces, were defined as the percentages in the population in each group. In addition, the aggregation of multiple agroecosystem health indicators into one integrative assessment of agroecosystem health make it easier to understand the complexity of the agroecosystem. The study has investigated whether, or how the two case study areas differed in agroecosystem health by aggregating the normalized values of key indicators. This study has shed significant new insights on agroecosystem health. Cross-national comparative research here serves as an essential tool in understanding the complexity of agroecosystem, and recognizing the effects of decision making by national governments. It also provides opportunities for targeted nations to learn lessons and exchange experience from each other in order to improve the quality of decision making for sustainability of agroecosytem.

6.4 Limitations and Recommendations

The sample size for the survey on the perceptions towards agroecosystem health, as well as the balance of the number of experts among disciplines of this research may have affected the results presented in Chapter 3. The balance of the number of Chinese experts among disciplines was a little skewed (i.e., proportionately more life sciences than other disciplines) in both rounds, compared to the Canadian mix of experts. In addition, the scale of research could be extended to more countries and the public could be included as survey respondents. The farmers and the policymakers, as well as other stakeholders, could be included as potential participants, for establishing a framework that incorporates knowledge and experience of all stakeholders that involves in the agroecosystem. We also recommend that future research take experts' genders, ages, social status and other factors, including their own experience with primary agriculture, personal attitude toward ecosystems and environmental issues, as well as their own subconscious views towards economic development: environmental sustainability, into account. Future studies should be focused on current environmental attitudes and values of the populations and how these attitudes change as the cultures vary.

Despite a concerted effort to develop approaches to estimate and model the targeted regional indicators, one of the limitations in this dissertation is the lack of direct data on agroecosystem health at local to regional scales. Also, there is a lack of time series data available for the key indicators at a sub-regional scale in the two regions. Therefore, further empirical research could be conducted to obtain subregional data and collect the time series data for the key agroecosystem health indicators. Since the study has utilized a series of secondary data from different countries, the measurements of the targeted indicators might be based on different contexts. However, the usefulness of combining GIS and census data sets shown here further underlines the benefit and in fact, need, for a complete dataset at the preferred scales (and dates).

In addition, it is impossible to include all aspects of indicators into one single research. The agroecosystem health indicators may vary in different social-ecological contexts, and at different scales. Therefore, the selection of key indicators of agroecosystem health framework is very critical to give an overall picture of agroecosystem health. Moreover, the evaluation of agroecosystem health can integrate both quantitative data, including remote sensing data, census data, and qualitative data, such as policy changes and social practices, to achieve a deeper understanding on how policy-making and social practices affect different components of agroecosystem health.

While the remote sensing works well on a larger scale, caution should be given when the remote sensing data is utilized for agroecosystem health evaluation at a smaller scale, e.g., farm and landscape. The low spatial resolution, lack of categorical precision, and low classification accuracy for many cover types have limited the evaluation precision. As well, local weather and climatic events close to the time the images were taken also have an impact on the changes in water body areas, which may affect the temporal analysis of soil erosion in targeted regions.

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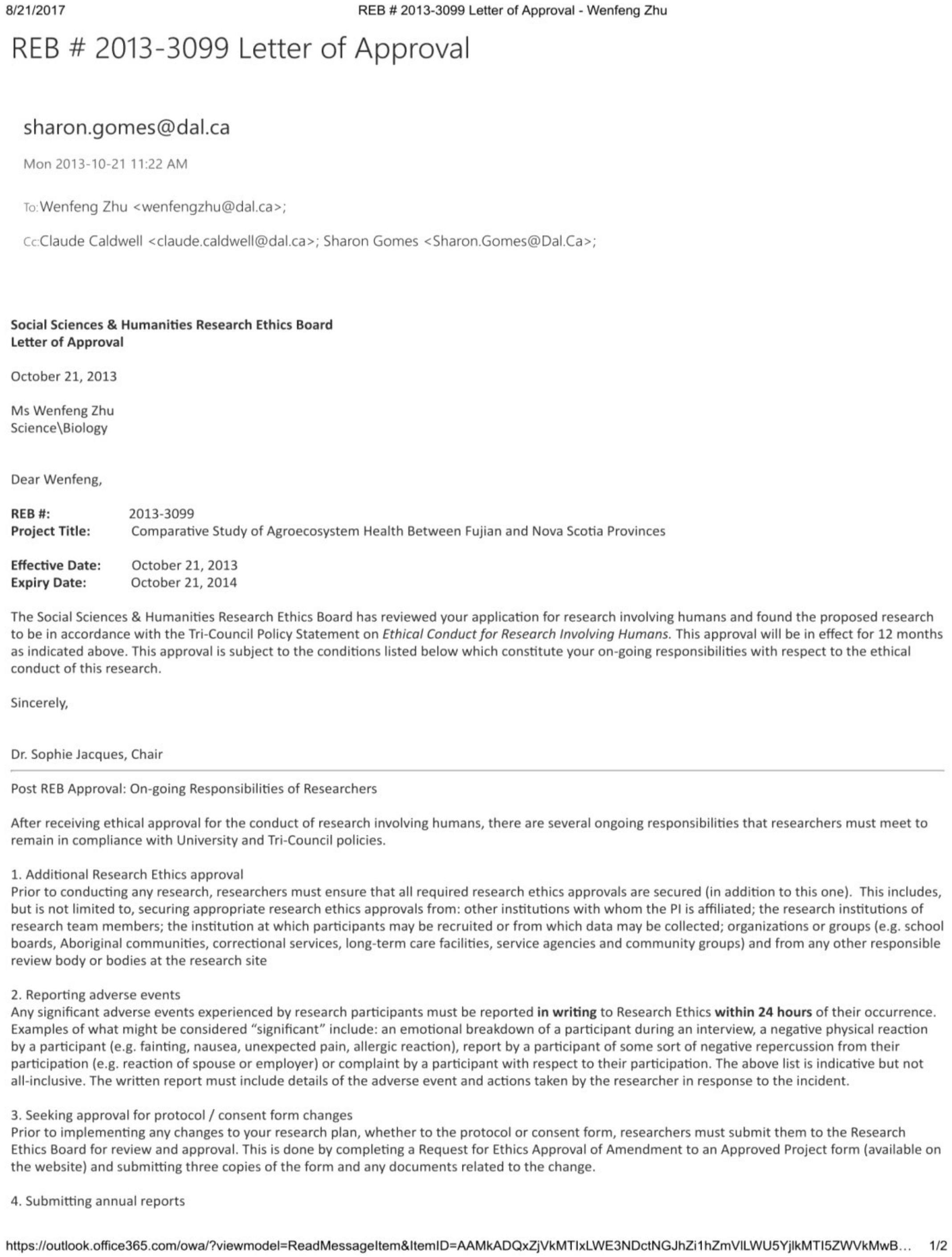
Appendices

Appendix A

A1. Letter of Approval from Research Ethics Board



8/21/2017 REB # 2013-3099 Letter of Approval - Wenfeng Zhu

REB # 2013-3099 Letter of Approval

sharon.gomes@dal.ca

Mon 2013-10-21 11:22 AM

To: Wenfeng Zhu <wenfengzhu@dal.ca>;

Cc: Claude Caldwell <claude.caldwell@dal.ca>; Sharon Gomes <Sharon.Gomes@Dal.Ca>;

Social Sciences & Humanities Research Ethics Board
Letter of Approval

October 21, 2013

Ms Wenfeng Zhu
Science\Biology

Dear Wenfeng,

REB #: 2013-3099
Project Title: Comparative Study of Agroecosystem Health Between Fujian and Nova Scotia Provinces

Effective Date: October 21, 2013
Expiry Date: October 21, 2014

The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans.* This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Sophie Jacques, Chair

Post REB Approval: On-going Responsibilities of Researchers

After receiving ethical approval for the conduct of research involving humans, there are several ongoing responsibilities that researchers must meet to remain in compliance with University and Tri-Council policies.

1. Additional Research Ethics approval
Prior to conducting any research, researchers must ensure that all required research ethics approvals are secured (in addition to this one). This includes, but is not limited to, securing appropriate research ethics approvals from: other institutions with whom the PI is affiliated; the research institutions of research team members; the institution at which participants may be recruited or from which data may be collected; organizations or groups (e.g. school boards, Aboriginal communities, correctional services, long-term care facilities, service agencies and community groups) and from any other responsible review body or bodies at the research site

2. Reporting adverse events
Any significant adverse events experienced by research participants must be reported **in writing** to Research Ethics **within 24 hours** of their occurrence. Examples of what might be considered "significant" include: an emotional breakdown of a participant during an interview, a negative physical reaction by a participant (e.g. fainting, nausea, unexpected pain, allergic reaction), report by a participant of some sort of negative repercussion from their participation (e.g. reaction of spouse or employer) or complaint by a participant with respect to their participation. The above list is indicative but not all-inclusive. The written report must include details of the adverse event and actions taken by the researcher in response to the incident.

3. Seeking approval for protocol / consent form changes
Prior to implementing any changes to your research plan, whether to the protocol or consent form, researchers must submit them to the Research Ethics Board for review and approval. This is done by completing a Request for Ethics Approval of Amendment to an Approved Project form (available on the website) and submitting three copies of the form and any documents related to the change.

4. Submitting annual reports

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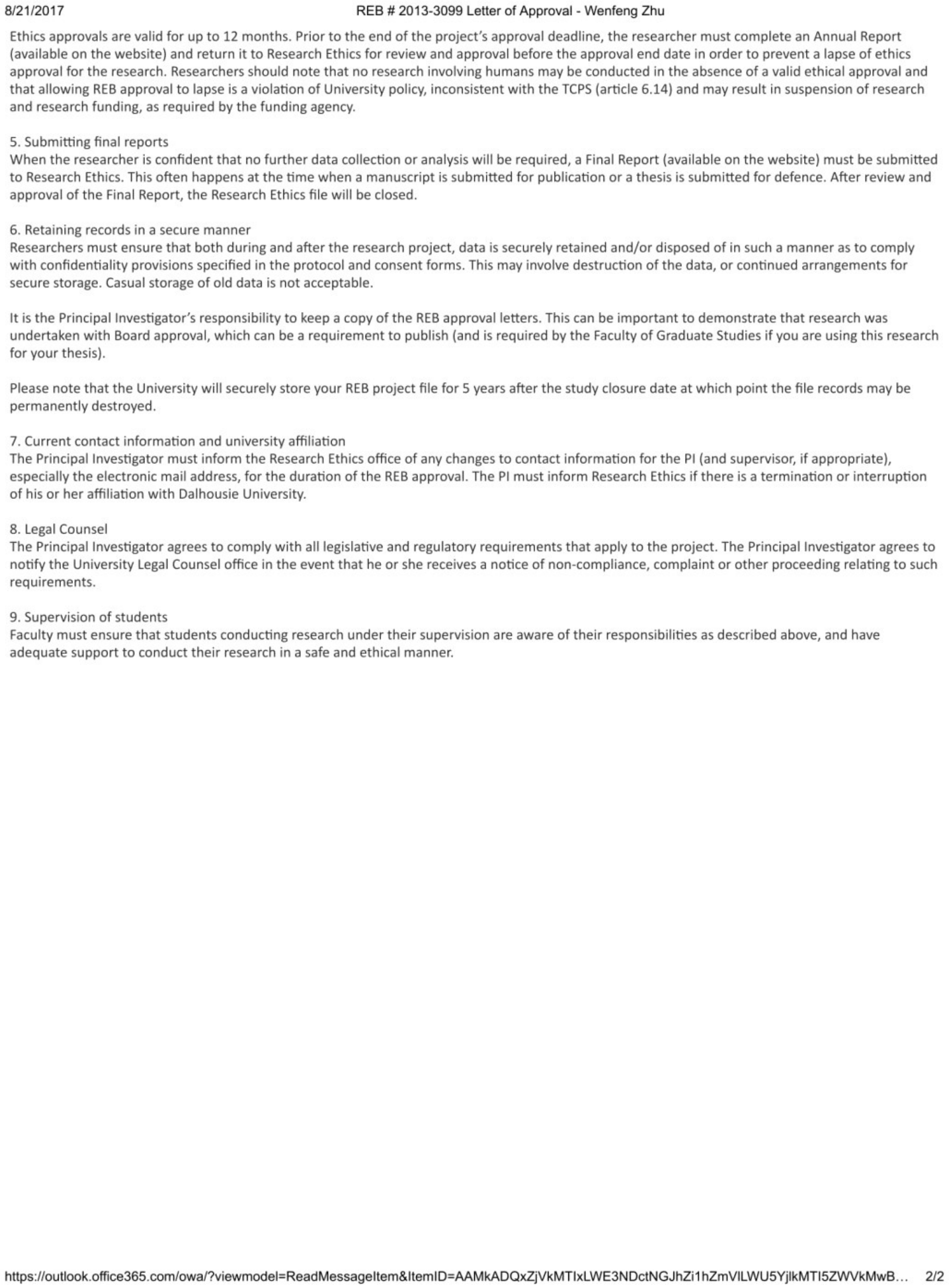

8/21/2017 REB # 2013-3099 Letter of Approval - Wenfeng Zhu

Ethics approvals are valid for up to 12 months. Prior to the end of the project's approval deadline, the researcher must complete an Annual Report (available on the website) and return it to Research Ethics for review and approval before the approval end date in order to prevent a lapse of ethics approval for the research. Researchers should note that no research involving humans may be conducted in the absence of a valid ethical approval and that allowing REB approval to lapse is a violation of University policy, inconsistent with the TCPS (article 6.14) and may result in suspension of research and research funding, as required by the funding agency.

5. Submitting final reports
When the researcher is confident that no further data collection or analysis will be required, a Final Report (available on the website) must be submitted to Research Ethics. This often happens at the time when a manuscript is submitted for publication or a thesis is submitted for defence. After review and approval of the Final Report, the Research Ethics file will be closed.

6. Retaining records in a secure manner
Researchers must ensure that both during and after the research project, data is securely retained and/or disposed of in such a manner as to comply with confidentiality provisions specified in the protocol and consent forms. This may involve destruction of the data, or continued arrangements for secure storage. Casual storage of old data is not acceptable.

It is the Principal Investigator's responsibility to keep a copy of the REB approval letters. This can be important to demonstrate that research was undertaken with Board approval, which can be a requirement to publish (and is required by the Faculty of Graduate Studies if you are using this research for your thesis).

Please note that the University will securely store your REB project file for 5 years after the study closure date at which point the file records may be permanently destroyed.

7. Current contact information and university affiliation
The Principal Investigator must inform the Research Ethics office of any changes to contact information for the PI (and supervisor, if appropriate), especially the electronic mail address, for the duration of the REB approval. The PI must inform Research Ethics if there is a termination or interruption of his or her affiliation with Dalhousie University.

8. Legal Counsel
The Principal Investigator agrees to comply with all legislative and regulatory requirements that apply to the project. The Principal Investigator agrees to notify the University Legal Counsel office in the event that he or she receives a notice of non-compliance, complaint or other proceeding relating to such requirements.

9. Supervision of students
Faculty must ensure that students conducting research under their supervision are aware of their responsibilities as described above, and have adequate support to conduct their research in a safe and ethical manner.

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A2. Survey Consent Form

Your participation in a research project, titled *"*Comparative study of Agroecosystem Health between Fujian and Nova Scotia Provinces,*"* is being requested.

My name is Wenfeng Zhu. I am a PhD student in the Department of Biology at Dalhousie University, Nova Scotia. I am conducting research for an independent project under the supervision or instruction of Dr. Claude Caldwell. My project is to be completed in partial fulfillment of my doctoral project. I would appreciate your participation in my research project

This project will develop frameworks and methods for evaluating ecosystem health status in agroecosystems. It will combine approaches from ecology, economics, sociology and biology to calculate the values of agroecosystems and to evaluate the health status of the natural ecosystem, social system and economic system, in an agroecosystem. In this process, the linkage between dynamic changes of agroecosystem health and human activities in the two provinces will be explored and main factors that threaten agroecosystem health will be identified. The aim of this research is to provide bases to inform agroecosystem management and policy decisions. It will also enhance the general public's awareness of protecting the environment. The expectation of this research is to describe examples of global and regional quantitative evaluation of ecosystems with a unique in-situ infrastructure. Therefore, this research is extremely significant since it can supply a guideline for policy making for agricultural development, in a sustainable way.

Your participation is voluntary, and you can withdraw at any time. All information received from you will be treated in confidence and with anonymity, and no individual responses will be attributed but merely aggregated into an overall report for this PhD project, and presented to related conferences. If you agree to participate in this research study, please electronically fill out the consent form attached to this e-mail and return it to me via e-mail.

I would like to thank you for sharing your time, knowledge and expertise for this study.

By signing this consent form, you are indicating that you fully understand the above information and agree to participate in this study.

Participant's signature ____

Date: ____

Researcher's signature: ____

Date: ____

If you have any questions contact me, Wenfeng Zhu, wn474408@dal.ca, 1-902-8936186. Or, contact my instructor or supervisor, Claude Caldwell, department of plant and animal since, Faculty of Agriculture at Dalhousie University, Claude.Caldwell@Dal.Ca, 1-902-8936680.

A3. Survey of Agroecosystem Health & Services Assessment Framework (Round one for both China and Canada)

Your Expertise

1. Which of the following terms is best describing your expertise?

A. Life Sciences B. Social Sciences C. Economic Science

Agroecosystem Health Indicators Selection

Agroecosystem health is a term introduced from medical science. It is an ideal condition in the process of agroecosystem variation with time and space. A healthy agroecosystem can keep itself from side-effects of occurrence of disorder syndrome, and it keeps vitality and diversity, coordinating its stability of the organizational structure and maintaining high productivity (Conway, 1985, 1987; Rapport, 1998).

Thinking about 10-15 indicators of Agroecosystem health from each aspect is preferred. I will use all your answers and thank you, regardless of how many indicators are provided.

2. What indicators can reflect agroecosystem health status from the perspective of Ecology?

3. What indicators can reflect agroecosystem health status from the perspective of Sociology?

4. What indicators can reflect agroecosystem health status from the perspective of Economics?

Agroecosystem Service Indicators Selection

Agroecosystem not only supplies steady material foundation and services of food products, but also has great environmental and social service value for human survival and development. Agroecosystem service is the value produced in agroecosystem process of changing sunlight into happy, healthy people (Caldwell, C. D and Kilyanek, S, 1996).

5. What ecological benefits/services do agroecosystems supply for us?

6. What social benefits/services do agroecosystems supply for us?

7. What economic benefits/services do agroecosystems supply for us?

A4. Survey of Agroecosystem Health & Services Assessment Framework (Round two - Canada)

1. Which of the following terms is best describing your expertise?

   A. Life Sciences B. Social Sciences C. Economic Science

2. Please prioritize the following ecological indicators in order of importance to agricultural ecosystem health status (1 being most important and 10 being least important).

- Soil quality _Erodability and contamination
- Soil quality_Soil organic matter content
- Air quality
- Water quality
- Energy_Availability of Energy
- Energy_Efficiency
- Biodiversity _Ratio natural habitat to manage
- Biodiversity _Diversity of plant, micro and macrofauna, genetic etc.
- Biodiversity_Land cover
- Others (If you consider an indicator that is not in this list to be of high importance, please add it to the following blank)

3. Please prioritize the following social indicators in order of importance to agricultural ecosystem health status (1 being most important and 10 being least important).

- Percent population above poverty line
- Percent rented land
- Fair return farm labour
- Rural community sustainability (level of emigration, health of people, level of education, gender structure, age structure etc.)
- Existence and activity of community organizations and associations
- Social diversity
- Extension services availability
- Happiness of people (job satisfaction)

- Gini index (index of inequality which could measure distribution of nutrition measures and calories per capita measures across population)
- Others (If you consider an indicator that is not in this list to be of high importance, please add it to the following blank)

4. Please prioritize the following economic indicators in order of importance to agricultural ecosystem health status (1 being most important and 11 being least important).

- Family income_ GDP per capita
- Family income_Income stability/resilience
- Farm income_ Profitability such as yield per hectare
- Farm income_Stability/resilience such as maintenance of infrastructure
- Farm debt
- Farm land values
- Health costs/expenditures per capita
- Education costs/expenditures per capita
- Value Chains_Food production
- Market prices of products
- Others (If you consider an indicator that is not in this list to be of high importance, please add it to the following blank)

A5. Survey of Agroecosystem Health & Services Assessment Framework (Round Two - China)

1. Which of the following terms is best describing your expertise?

   A. Life Sciences B. Social Sciences C. Economic Science

2. Please prioritize the following ecological indicators in order of importance to agricultural ecosystem health status (1 being most important and 10 being least important).

- Soil organic matter
- Soil contamination
- Agricultural productivity
- Soil erosion
- Water quality
- Biodiversity
- Natural resources and ability
- Vegetation coverage
- Air quality
- Protection measures
- Others (If you consider an indicator that is not on this list to be of high importance, please add it to the following blank)

3. Please prioritize the following social indicators in order of importance to agricultural ecosystem health status (1 being most important and 10 being least important).

- Food safety
- Human health
- Ecological compensation mechanism
- Education and training
- Population structure
- Public infrastructure and service
- Happiness index
- Fairness and equality
- Engel coefficient

- Rural urbanization
- Others (If you consider an indicator that is not on this list to be of high importance, please add it to the following blank)

4. Please prioritize the following economic indicators in order of importance to agricultural ecosystem health status (1 being most important and 11 being least important).

- Energy and resource efficiency
- Intensity of using pesticide and fertilizer
- Resource self-supporting
- Agricultural infrastructure
- Production efficiency
- Food self-supporting
- Diversity or number of crop varieties
- Industrial structure and business model
- Income of agricultural population
- Gap between the rich and the poor
- Others (If you consider an indicator that is not on this list to be of high importance, please add it to the following blank)

Appendix B

1. Soil erosion model

The Revised Universal Soil Loss Equation (RUSLE) was integrated with GIS technology to assess the potential risk and estimated rates of soil erosion in Nova Scotia and Fujian Province. The RUSLE has been widely used to predict the average annual soil loss. It considers factors that interact with and affect soil erosion, including topography, climate, soil, vegetation, land use and human activities. The RUSLE model is expressed as follows:

$$\mathrm{A} = \mathrm{R} * \mathrm{K} * \mathrm{LS} * \mathrm{C} * \mathrm{P} \qquad \text{Equation 1}$$

Where:

A: Estimated rate of soil erosion (t ha^{-1} yr^{-1}),

R: Rainfall Erosivity factor (MJ mm^{-1} ha^{-1} h^{-1} yr^{-1}),

K: Soil Erodibility factor (t h MJ^{-1} mm^{-1}),

LS: Slope Length and Slope Steepness factor (dimensionless),

C: Cover-Management factor (dimensionless, range from 0 - 1),

P: Support practices factor (dimensionless, range from 0 - 1).

2. Data Sets and Map Preparation

2.1 Basic watershed map

A watershed shapefile map of Nova Scotia at a scale of 1:10,000 was obtained from the website of the Government of Nova Scotia. The Shapefile map of Fujian is from the China Administrative Regions GIS Data: 1:1M, County Level, which is composed of boundary files covering the administrative regions of China. These basic watershed shape files were utilized to extract the required data from Global Soil Data, Landcover Data and Rainfall Data.

2.2 Meteorological map/data

The rainfall data were obtained from the satellite products provided by Tropical Rainfall Measuring Mission (TRMM), which is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA). The TRMM satellite has produced more than 17 years (1998-2016) of valuable scientific data for weather and climate research (Huffman *et al.*, 2007). The Monthly TRMM rainfall data (3B43) for each county for fourteen years (January 1998 to January 2016) were extracted from TRMM data based using the Giovanni tool. Giovanni is a NASA Goddard online visualization and analysis tool (http://giovanni.gsfc.nasa.gov). This web tool allows users to compare and analyze online multi-sensor remote sensing data without downloading a massive data set, which shortens the time for downloading and processing the data.

2.3 Soil erodibility map layer

The Harmonized World Soil Database does not contain the direct information of soil texture class and organic matter content. However, the database includes soil information of sand, silt and clay content and organic carbon content, which can be transformed into the information needed for this project, to estimate the soil erodibility factor (Nachtergaele *et al*., 2009). This database is a 30 arc-second raster database, with over 15,000 different soil mapping units that combines existing regional and national updates of soil information worldwide with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World.

2.4 Digital Elevation Model (DEM) map/data

Digital Elevation Model maps for Nova Scotia and Fujian (Figure B1 and Figure B2) were extracted from global DEM data, which is provided by the NASA Shuttle Radar Topographic Mission (SRTM). The SRTM digital elevation data was produced by NASA initially. The SRTM elevation data has a resolution of 90 m at the equator, and are provided in mosaicked 5 deg x 5 deg tiles for easy download and use (Jarvis *et al*., 2008).

2.5 Land cover map/data

The land cover data were obtained from the results of the GlobCover Project, which was carried out by The European Space Agency portal (http://due.esrin.esa.int/page_globcover.php). The land cover products are an ESA initiative, which began in 2005 in cooperation with FAO, JRC, EEA, UNEP, GOFC-GOLD and IGBP. This project developed a service that delivers global composites and land cover maps, using input observations from the 300m MERIS sensor on board the ENVISAT satellite mission. This ESA land cover data set contains two periods of data (December 2004 to June 2006 and January to December 2009). The land cover data (Figure B3 and Figure B4) were used as the basic map for the determination of land cover factors. The value codes for the land cover type are listed and reclassified as presented in Table B1. However, this database had a trend to overestimate forest areas when the data coverage is poor and the identification of water bodies is limited on -60° and +60° of latitude (Bicheron *et al*., 2008).

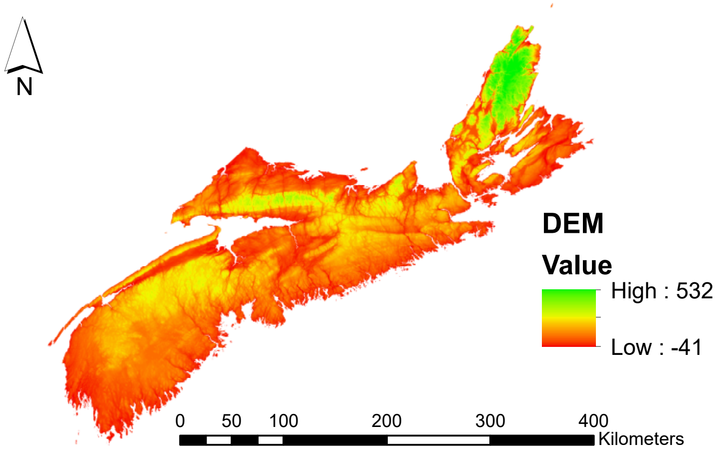


Figure B1 DEM in Nova Scotia

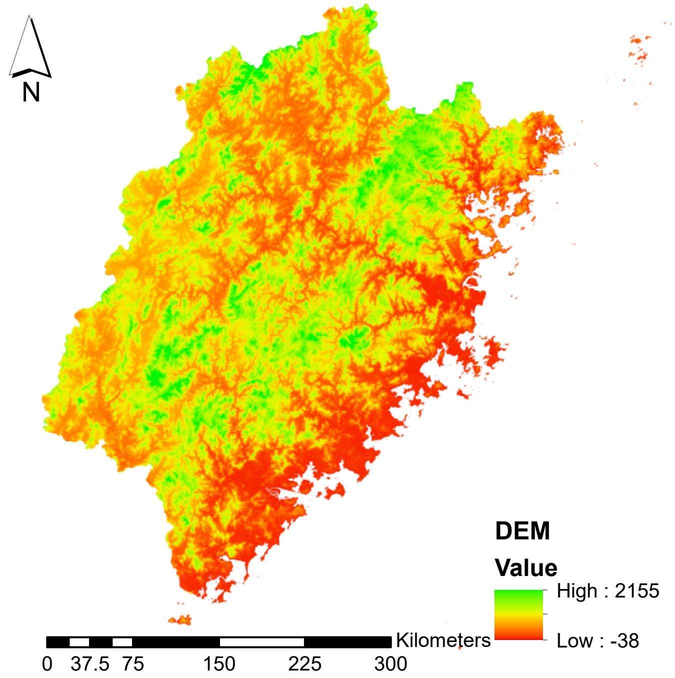


Figure B2 DEM in Fujian

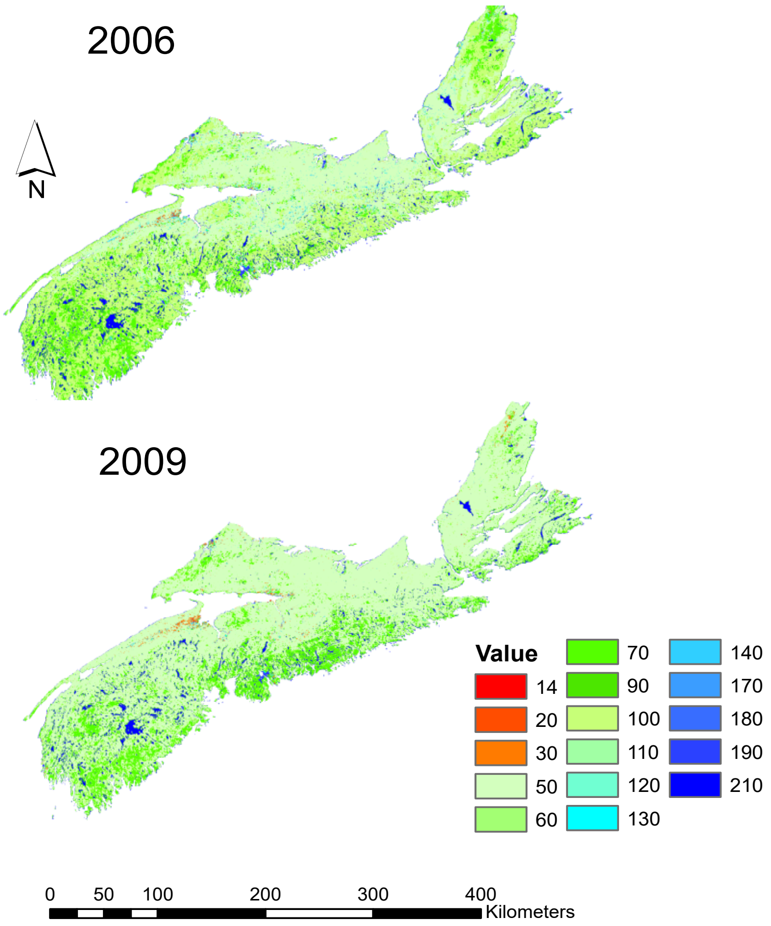


Figure B3 Landover in Nova Scotia

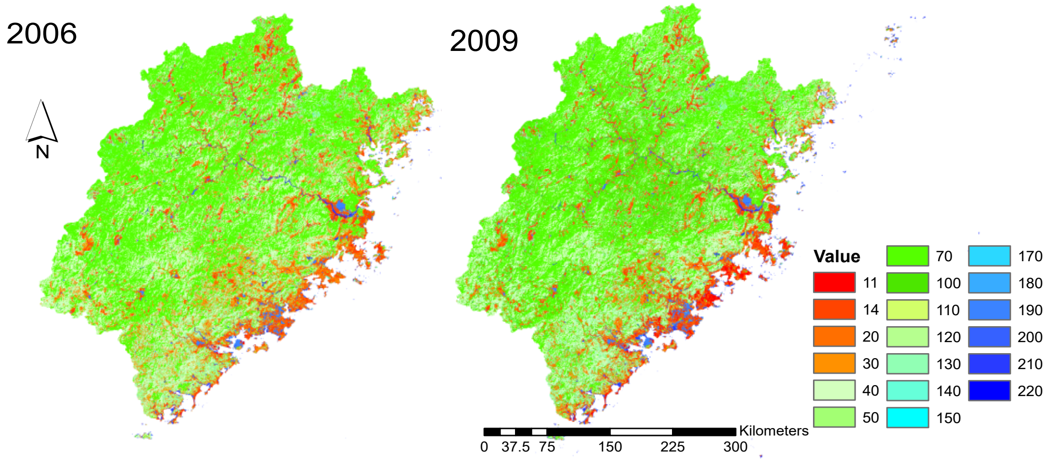


Figure B4 Landover in Fujian

Table B1 Cover type code for land use classification

Value	Land use classes	Reclassified Land use classes
11	Post-flooding or irrigated croplands (or aquatic)	Agricultural land use
14	Rainfed croplands	
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	Forest
50	Closed (>40%) broadleaved deciduous forest (>5m)	
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	
70	Closed (>40%) needle leaved evergreen forest (>5m)	
90	Open (15-40%) needle leaved deciduous or evergreen forest (>5m)	
100	Closed to open (>15%) mixed broadleaved and needle leaved forest (>5m)	
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	
130	Closed to open (>15%) (broadleaved or needle leaved, evergreen or deciduous) shrubland (<5m)	
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	
150	Sparse (<15%) vegetation	Sparse (<15%) vegetation
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	Mosaic forest or shrub land or grass
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	
190	Artificial surfaces and associated areas (Urban areas >50%)	Bare areas
200	Bare areas	
210	Water bodies	Water bodies
220	Permanent snow and ice	Permanent snow and ice
		No data (burnt areas, clouds)

3. Factors Estimation and Map Processing

3.1 The rainfall erosivity factor (R)

Rainfall erosivity is an important parameter for soil erosion assessment. It reflects the effect of rainfall intensity and amount on soil erosion (Essel, *et al*., 2016). The most commonly used method for determining rainfall erosivity factor is based on EI30, where E represents the total storm kinetic energy and I30 represents the maximum 30-min rainfall intensity (Renard *et al*., 1997). According to Wischmeier and Smith (1978), in order to estimate storm E130 values, at least 20 years of continuous rainfall intensity data are required. There is, however, a lack of available 30-min rainfall intensity data at standard meteorological stations for most parts of the world. Therefore, average annual and monthly have been increasingly taken into account for estimating the rainfall erosivity (Yu & Rosewell, 1996; Horvath, Réti & Rosian, 2016).

Fournier (1960) created an index indicating climatic aggressiveness, based on monthly and yearly precipitations. The Fournier index formula is:

$\mathrm{FI} = \frac{\mathrm{p_{max}}^2}{\mathrm{p}}$ (Equation 3)

Where Fi is the Fournier Index, p is the monthly rainfall (mm), and P the annual rainfall (mm).

Later research disclosed that the Fournier index is correlated to other climatic variables which also contribute the amount of sediment washed into the stream by runoff. In 1980, Arnoldus adapted the Fournier index and changed the formula into:

$\mathrm{FM} = \sum_{\mathrm{i}=1}^{12} \frac{\mathrm{p_i}^2}{\mathrm{p}}$ (Equation 4)

FM is the Modified Fournier Index, Pi is the average monthly precipitation (mm), and P is the average annual precipitation (mm). The FM index has been approved as a good approximation of R (rainfall erosivity). Yu & Rosewell (1996) indicated a high correlation between the modified Fournier index and the R-factor (Rainfall factors) and proposed the formula for calculating R factor based on the modified Fournier index:

$\mathrm{R} = 3.82\mathrm{F}^{1.41}$(Equation 5)

To assess the R-factor in Nova Scotia and Fujian, 62 observation points were chosen in Fujian province and 66 observation points were chosen in NS, according to the geographic locations of the climate stations that were randomly distributed within the study areas. The spatial distribution of the data achieved from these stations is shown in (Figure B5 and Figure B6). Monthly rainfall data (3B43) for two study periods (January 1998 to January 2006, and January 2006 to January 2016) were used to compute annual rainfall erosivity indices for the selected observation stations, through the adoption of the MFI (Equations 4 and 5). The stations' longitude/latitude and the annual rainfall are listed in Table B2 and Table B3. The values of the R factor estimated for each selected station were exported into the GIS and a Kriging interpolation method was utilized to interpolate the rainfall erosivity factor maps of NS and Fujian.

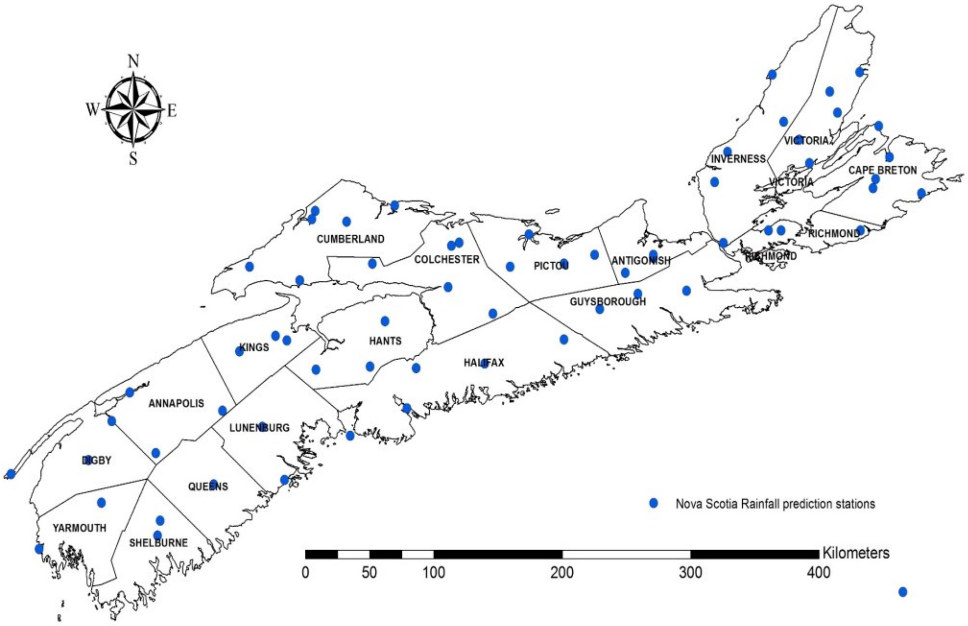


Figure B5 Nova Scotia Rainfall prediction stations

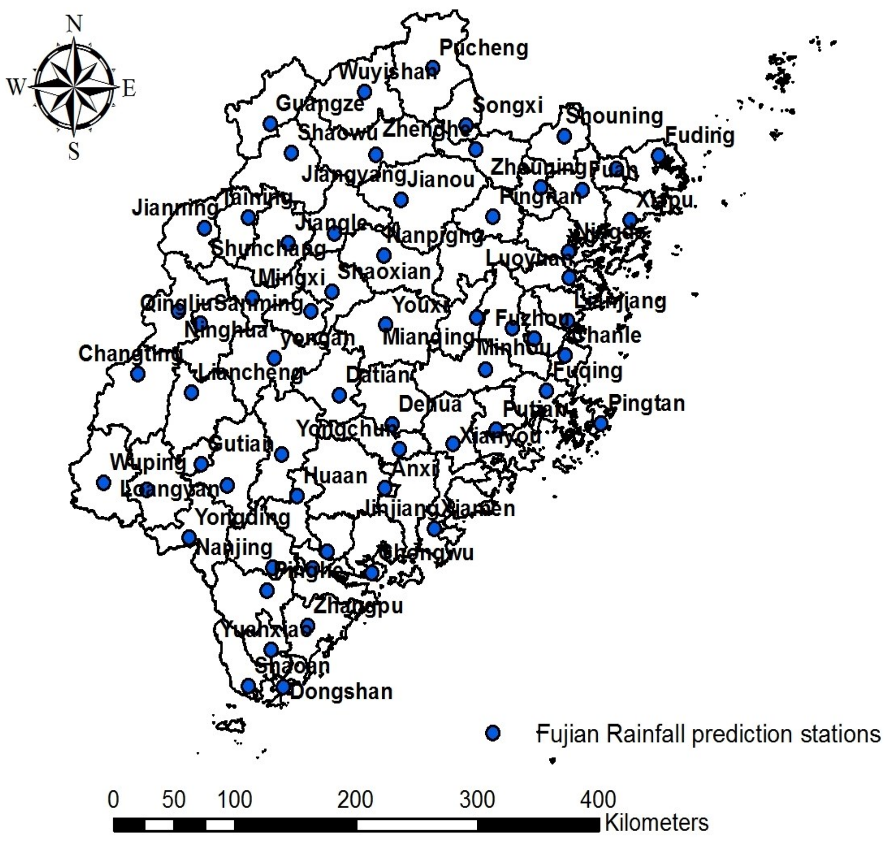


Figure B6 Fujian Rainfall prediction stations

Table B2 The rainfall erosivity factor of Nova Scotia

FID	Station Name	Latitude	Longitude	Annual rainfall	R_98-06	R_07-15
1	Greenwood	34.17	-82.13	980	1019	989
2	Collegeville	40.19	-75.45	1135	1215	1182
3	Bridgewater	40.59	-74.6	1536	1155	1145
4	Westport	44.26	-66.35	1015	1169	1382
5	Yarmouth	43.82	-66.15	1170	1062	968
6	Digby	44.34	-65.8	1427	1304	1676
7	Yartmouth	44.09	-65.72	1420	1288	1610
8	Bear River	44.57	-65.64	1172	1309	1765
9	Annapolis Royal	44.74	-65.52	1026	1309	1765
10	Kejimkujik National Park	44.38	-65.33	1348	1381	1854
11	Shelburne	43.89	-65.32	1363	1193	1319

FID	Station Name	Latitude	Longitude	Annual rainfall	R_98-06	R_07-15
12	Queen	44.2	-64.93	1520	1374	1709
13	Springfield	44.63	-64.87	1210	1341	1642
14	Kings	44.99	-64.75	1143	1161	1323
15	Cumberland	45.49	-64.68	1326	1161	1323
16	Lunenburg	44.54	-64.59	1495	1345	1636
17	Kentville	45.08	-64.49	1181	1221	1379
18	Liverpool Big Falls	44.22	-64.43	1382	1383	1751
19	White Rock	45.05	-64.42	1033	1175	1330
20	Parrsboro	45.41	-64.33	1079	1175	1330
21	Parrsboro	45.41	-64.33	1270	1175	1330
22	Nappan	45.77	-64.24	978	1101	1193
23	Amherst - Nappan	45.82	-64.22	1155	1101	1193
24	Huants	44.88	-64.21	1447	1289	1496
25	St Margaret's Bay	44.49	-63.97	1301	1364	1617
26	Mount Uniacke	44.9	-63.83	1370	1265	1472
27	Colchester	45.51	-63.82	1302	1125	1211
28	Huants	45.17	-63.73	1372	1204	1329
29	Pugwash	45.85	-63.66	1038	1075	1142
30	Halifax	44.65	-63.58	1468	1329	1495
31	Halifax Stanfield	44.89	-63.51	1333	1266	1465
32	Truro	45.37	-63.29	1028	1184	1263
33	Colchester	45.61	-63.26	1314	1145	1220
34	Colchester	45.63	-63.21	1334	1173	1249
35	Halifax	44.91	-63.03	1468	1315	1435
36	Upper Stewiacke	45.21	-62.97	1173	1290	1350
37	Pictou	45.49	-62.85	1380	1244	1268
38	Pictou	45.68	-62.72	1232	1238	1241
39	Halifax	45.06	-62.48	1468	1252	1171
40	Pictou	45.56	-62.26	1232	1182	1111
41	Antigonish	45.45	-62.05	1364	1223	1155
42	Guysborough	45.33	-61.96	1286	1223	1155

FID	Station Name	Latitude	Longitude	Annual rainfall	R_98-06	R_07-15
43	Antigonish	45.54	-61.85	1298	1123	1090
44	Inverness	45.99	-61.42	1499	1227	1185
45	Port Hawkesbury	45.63	-61.36	1384	1213	1175
46	Inverness	46.17	-61.33	1499	1319	1291
47	Richmond	45.7	-61.04	1395	1266	1180
48	Cheticamp	46.63	-61.01	1375	1298	1176
49	Richmond	45.7	-60.95	1422	1459	1426
50	Inverness	46.35	-60.94	1499	1458	1411
51	Victoria	46.24	-60.83	1514	1162	1132
52	Baddeck	46.1	-60.75	1535	1458	1411
53	Victoria	46.53	-60.61	1506	1477	1428
54	Victoria	46.4	-60.56	1527	1513	1467
55	Ingonish Beach	46.64	-60.4	1753	1451	1373
56	Richmond	45.7	-60.4	1430	1327	1157
57	Cape Breton	45.95	-60.31	1439	1347	1199
58	Cape Breton	46.01	-60.29	1516	1487	1386
59	Wreck Cove Brook	46.32	-60.27	1423	1489	1407
60	Sydney	46.14	-60.19	1299	1405	1279
61	Sable Island	43.56	-60.1	1503	1601	1472
62	Louisbourg	45.92	-59.97	1646	1045	957

Note: Some of the places are from the same place but with different Latitude and Longitude.

Table B3 The rainfall erosivity factor of Fujian Province

FID	Station Name	Latitude	Longitude	Annual rainfall	R_98-06	R_07-15
1	Guangze	27.54	117.33	2293	4150	3704
2	Shaowu	27.34	117.49	2428	4063	3673
3	Wuyishan	27.76	118.04	2162	4089	3656
4	Pucheng	27.92	118.54	1943	3767	3549
5	Jiangyang	27.33	118.12	2289	4094	3454
6	Songxi	27.53	118.79	1919	3731	3211

FID	Station Name	Latitude	Longitude	Annual rainfall	R_98-06	R_07-15
7	Zhenghe	27.37	118.86	1833	3696	3159
8	Jianou	27.02	118.31	2303	3895	3217
9	Shouning	27.45	119.52	2384	3381	2937
10	Zhouning	27.1	119.34	2686	3280	2906
11	Fuan	27.09	119.65	1960	3193	2840
12	Tuorong	27.23	119.9	2285	3145	2689
13	Fuding	27.32	120.22	2039	2968	2596
14	Ninghua	26.26	116.65	1806	3400	3172
15	Qingliu	26.18	116.82	1759	3244	3106
16	Taining	26.9	117.18	2318	3453	3094
17	Jiangle	26.73	117.47	1943	3383	3112
18	Jianning	26.83	116.85	2011	3516	3230
19	Shunchang	26.79	117.81	2036	3541	3129
20	Mingxi	26.36	117.2	1833	3235	3054
21	Shaoxian	26.4	117.79	1807	3165	2976
22	Sanming	26.26	117.64	1742	3217	2973
23	Nanpigng	26.64	118.18	2046	3488	3169
24	Gutian	25.22	116.82	1716	2623	3003
25	Youxi	26.17	118.19	1758	2954	2978
26	Mianqing	26.22	118.86	1506	2673	2876
27	Xiapu	26.89	120.01	1800	2938	2040
28	Minhou	26.15	119.13	1486	2594	2764
29	Luoyuan	26.49	119.55	1901	2523	2545
30	Ningde	26.67	119.55	2430	2850	2706
31	Fuzhou	26.07	119.3	1628	2344	2473
32	Lianjiang	26.2	119.54	1639	2259	2291
33	Changting	25.83	116.36	1421	2895	3012
34	Liancheng	25.71	116.75	1493	2637	2931
35	Wuping	25.1	116.1	1463	2524	2891
36	Shanghang	25.05	116.42	1435	2616	3013
37	yongan	25.94	117.37	1400	2757	2739

FID	Station Name	Latitude	Longitude	Annual rainfall	R_98-06	R_07-15
38	Datian	25.69	117.85	1269	2489	2787
39	Zhangping	25.29	117.42	1365	2515	2643
40	Loangyan	25.08	117.02	1725	2646	2832
41	Huaan	25	117.53	1452	2628	2768
42	Anxi	25.06	118.19	1295	2453	2774
43	Yongtai	25.87	118.93	1334	2338	2745
44	Pingnan	26.91	118.99	2196	3242	2999
45	Yongchun	25.32	118.29	1495	2504	3130
46	Dehua	25.49	118.24	1466	2572	3083
47	Xianyou	25.36	118.69	1529	2326	2803
48	Chanle	25.96	119.52	1403	1950	1835
49	Fuqing	25.72	119.38	1139	1845	1871
50	Pingtan	25.5	119.79	926	1966	2021
51	Putian	25.45	119.01	1361	1800	1808
52	Yongding	24.72	116.73	1705	2583	3049
53	Changtai	24.63	117.76	1560	2638	2357
54	Nanjing	24.51	117.36	1643	3006	2943
55	Pinghe	24.36	117.31	1422	3014	2751
56	Zhangzhou	24.51	117.65	1614	2888	2779
58	Zhangpu	24.12	117.61	1149	2652	2351
61	Chongwu	24.48	118.09	771	2262	1878
62	Xiamen	24.78	118.55	1085	1926	1673
63	Jinjiang	24.78	118.55	972	1926	1673
64	Shaoan	23.71	117.18	1272	2358	2161
65	Dongshan	23.7	117.43	953	2116	1903
66	Yuanxiao	23.96	117.34	1583	2347	2032

3.2 The soil erosivity factor (K)

The soil erodibility factor (K-factor) in USLE model represents the inherent erodibility of soil textural classes with a different structure, organic matter, and permeability. It measures the vulnerability of soil particles to detach and transport when affected by rainfall and runoff (Mitchell *et al*., 1980). The K-factor reflects the effect of soil properties and soil profile characteristics on soil erosion. Soil texture is the most important factor affecting K, but others, including soil profile, permeability and organic matter, should also be taken into account. The K-factor is commonly calculated by the soil erodibility monograph, which was proposed by Wischmeier and Smith (1978). The formula considers five soil parameters, including texture, organic matter, structure, coarse fragments, and permeability.

$$\mathrm{K} = 27.66 * \mathrm{m}^{1.14} * 10^{-8} * (12 - \mathrm{a}) + \big(0.0043 * (\mathrm{b} - 2)\big) + (0.0033 * (\mathrm{c} - 3)$$

Where:

- K is soil erodibility factor (t*ha/MJ*mm);
- m is (silt (%) + very fine sand (%)) (100-clay (%));
- a is organic matter (%);
- b is structure code; (1) very structured or particulate, (2) fairly structured, (3) slightly structured and (4) solid;
- c is profile permeability code: (1) rapid, (2) moderate to rapid, (3) moderate, (4) moderate to slow, (5) slow and (6) very slow.

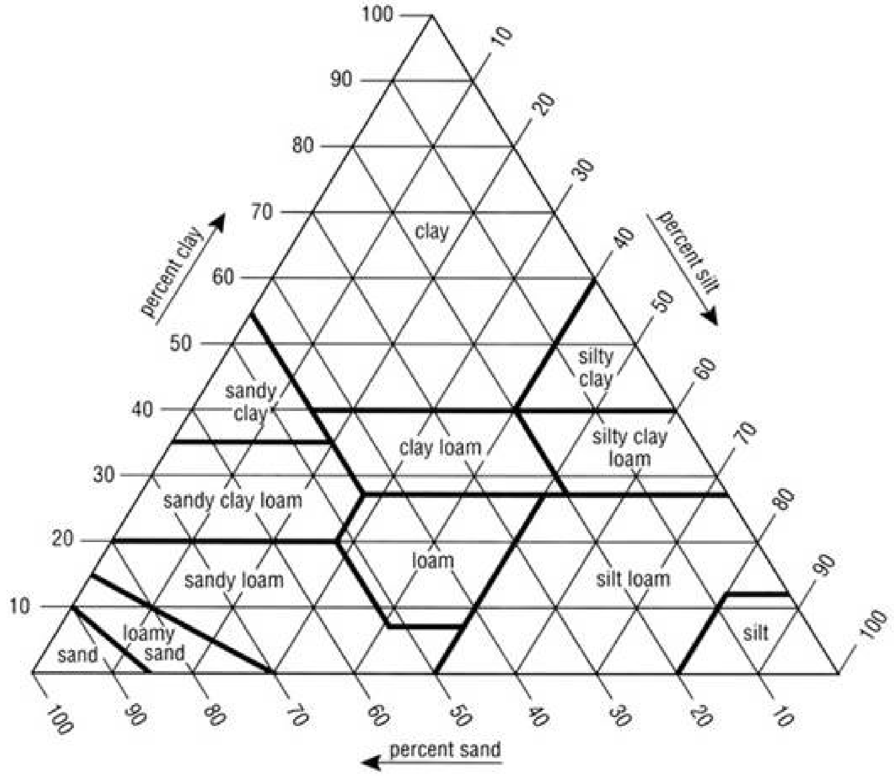
However, the formula is only applicable to those cases where profile permeability and structure are not available, which limits its application in a watershed or on a global scale. Roose (1996) noted that soil erodibility could be estimated based on soil texture and organic matter content, as shown in Table B4.

In this study, Table B4 was utilized as the reference to determine the soil erosivity factor (K). The data for the percentages of clay, silt, and sand in soil, as well as organic carbon content from the two provinces, were extracted from Harmonized World Soil Database. Since the percentages of clay, silt, and sand in soil were known, a textural triangle (Figure B7) was used to determine the texture class of the soil in the two provinces. Then, organic carbon contents were converted to organic matter by multiplying by a factor of 1.72 (Rhoton *et al*., 2002). These soil data were then put into the attribute database of the soil map layer in GIS. Then, the K-factors were determined for each soil mapping unit in GIS. The spatial distribution of the K-factor maps for the two regions were created.

Table B4 Soil erosivity factor (K) estimation values based on texture and organic matter content

Soil Texture Class	**Soil Composition**			**Mean K (based on % of organic matter)**		
	Sand	**Silt**	**Clay**	**Unknown**	**< 2%**	**> 2%**
Clay	0-45	0-40	40-100	0.22	0.24	0.21
Sandy Clay	45-65	0-20	35-55	0.2	0.2	0.2
Silty Sand	0-20	40-60	40-60	0.26	0.27	0.26
Sand	86-100	0-14	0-10	0.02	0.03	0.01
Sandy Loam	50-70	0-50	0-20	0.13	0.14	0.12
Clay Loam	20-45	15-52	27-40	0.3	0.34	0.26
Loam	23-52	28-50	7-27	0.3	0.34	0.26
Loamy Sand	70-86	0-30	0-15	0.04	0.05	0.04
Sandy Clay Loam	45-80	0-28	20-35	0.2	0.2	0.2
Silty Clay Loam	0-20	40-73	27-40	0.32	0.35	0.3
Silt	0-20	88-100	0-12	0.38	0.41	0.37
Silt Loam	20-50	74-88	0-27	0.38	0.41	0.37

Note: edited from Roose (1996).



The Soil Texture Triangle describes the relative proportions of sand, silt and clay in different types of soils.

Source: http://soils.usda.gov/technical/manual/print_version/complete.html

Figure B7 The soil texture triangle

3.3 Slope length and steepness (LS) factor

The slope length and steepness (LS) factor accounts for the effect of terrain on erosion, includes slope steepness (S) and slope length (L) factors. It has been demonstrated that erosion usually increases with slope steepness (S) and slope length (L). Slope steepness (S) is believed to have more obvious effects on soil erosion, compared with slope length (L) (McCool *et al*., 1987).

In this study, S factor was computed according to the following formulae (Wischmeier & Smith; Anton *et al*, 2014):

$$S = \begin{cases} 10.8\sin\theta + 0.03 & \theta < 5° \\ 16.8\sin\theta - 0.5 & 5° \le \theta < 10° \\ 21.91\sin\theta - 0.96 & \theta \ge 10° \end{cases} \quad \text{(Equation 6)}$$

Where:

S is the slope steepness factor; θ is the slope angle.

L factor could be calculated according to Moore and Burc's formulas:

$L = (\frac{l}{22.13})^m$ where：

$$m = \begin{cases} 0.5 & \beta \ge 5\% \\ 0.4 & 3\% \le \beta < 5\% \\ 0.3 & 1\% \le \beta < 3\% \\ 0.2 & \beta < 1\% \end{cases} \quad \text{(Equation 7)}$$

Where:

β represents Steepness (%)

While $l_i = \sum_1^i (D_i / \cos\theta_i) - \sum_1^{i-1} (D_i / \cos\theta_i) = D_i / \cos\theta_i$

Where l_i is slope length of pixel, D_i is horizontal projection distance of slope length per pixel in the direction along run off the (is two adjacent pixel center distances in raster images and it varies with direction), θ_i the slope for each image pixel (°), i is number of unknown pixels and ridge pixels.

The first step for calculating LS factor was as follows:

- Resample the DEM file, setting the resolution as 90 m* 90 m;
- Calculate the slope angle θ based on DEM map of the two study areas using raster "slope" functions of ArcGIS;
- Calculate the S factor by using raster calculation based on Equation 6;
- Fill the value which was missing in the DEM raster file using "Fill" function of GIS;

- Use “Flow Direction” tool of spatial analysis function of GIS to obtain the D Values Flow Direction made the elevation (DEM) raster of flow direction from each cell to its steepest downslope neighbor;
- Use raster calculation based on Equation 7 to get the l values;
- Use “Slope” tool to calculate θi and to calculate so m values using “raster calculation” tool based on Equation 8;
- With the l and m known, use raster calculation based on Equation 4.7 to determine L factor;
- Multiply S to L factors to get the LS factor values;

Through these processes, the LS factor is calculated for the target area.

3.4 Cover Management factor (C)

The Cover Management Factor (C) is used to determine the effect of land use types and land cover percentage on soil erosion rate (Renard *et al.*, 1997). The C factor accounts for the effects of the land cover types and coverage ratio on the soil erosion. On a small field scale, C factor is often determined through experimental field observation. However, it is impossible to obtain the field experimental data for a watershed or on a regional scale. The development of remote sensing technologies advances the progress of the estimation of C factor in a watershed and even on a global scale in a more detailed and accurate way. Using a RS image of land use, the C factor can be determined by identifying the land cover types and a coverage ratio of the study areas. Values of C factor vary from between 0 and 1 and the greater the value, the higher estimated rate of soil loss.

In this research, the land use data that contain two periods of data (December 2004 to June 2006, and January to December 2009) were extracted from the ESA land cover database. The maps of land use of the two study areas were prepared; the map area associated with each land use-land cover class was calculated and C-factors were assigned, according to Table B5. The table list the C-factor values for each land use category, which were proposed by Kim *et al*. (2005). The values of C factor were exported into GIS and C factor maps for the two targeted areas for two periods (December 2004 to June 2006, and January to December 2009) were created.

Table B5 C factor value for different land use categories

Value	Land use classes	C values
11	Post-flooding or irrigated croplands (or aquatic)	0.1800
14	Rainfed croplands	0.2663
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	0.2323
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	0.1232
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	0.0017
50	Closed (>40%) broadleaved deciduous forest (>5m)	0.0009
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	0.0013
70	Closed (>40%) needle leaved evergreen forest (>5m)	0.0009
90	Open (15-40%) needle leaved deciduous or evergreen forest (>5m)	0.0011
100	Closed to open (>15%) mixed broadleaved and needle leaved forest (>5m)	0.0012
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	0.0316
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	0.0435
130	Closed to open (>15%) (broadleaved or needle leaved, evergreen or deciduous) shrubland (<5m)	0.0623
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	0.0420
150	Sparse (<15%) vegetation	0.2652
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	0.0013
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	0.0009
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	0.0435
190	Artificial surfaces and associated areas (Urban areas >50%)	0.1000
200	Bare areas	0.3427
210	Water bodies	0.0100
220	Permanent snow and ice	0.0000
230	No data (burnt areas, clouds)	0.3427

*Adapted from Wischmeier and Smith (1978), Renard *et al*., 1997; ** Calculation from Morgan (1995)

3.5 Supportive practice factor (P)

The Support Practice Factor (P) in RUSLE is defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with straight row upslope and downslope tillage. Values of P factor vary between 0 and 1 and the greater the value; the higher is the estimated rate of soil loss. In this study, the areas without supporting practices were assigned a value as 1.0. The P value of the areas with supporting practices was determined based on the relation between the supporting mechanical practice and slope in the study areas as presented in Table B6 (Shin, 1999). The supporting mechanical practices include the effects of contouring, strip cropping, or terracing (Kim, 2006).

In Fujian province, all three supporting practices are distributed in the agricultural land use area. Thus, the mean value of the three categories was calculated to determine the P factor values in Fujian province, as shown in Table B7. With regard to Nova Scotia, strip cropping was the only supporting practice; therefore, the values for strip cropping were utilized to assign P factor values in this area (Table B7).

Table B6 P factor values for different supporting practices with area with different slopes

Slope (%)	Contouring	Strip Cropping	Terracing
0.0 – 7.0	0.55	0.27	0.10
7.0 – 11.3	0.60	0.30	0.12
11.3 – 17.6	0.80	0.40	0.16
17.6 – 26.8	0.90	0.45	0.18
> 26.9	1.00	0.50	0.20

By using the “Lookup” (Spatial Analyst) tools of GIS, the agricultural land use raster files were created, using the values of 11, 14, 20 and 30 from the land use data. Then, using the “Mask” function, the extracted agricultural land use maps were utilized as the mask layers to extract the required area from the slope maps, which were created when the LS factor maps were developed. Then, the values were assigned to the masked slope maps for agricultural land use, according to Table B7. The P factor maps of the agricultural areas were created. Then, using the “raster calculation” tool, all the no data areas were assigned a value of 1, since there was no supporting practice implement in other land use categories. Then, the final P factor maps for the study areas were obtained.

Table B7 P factor values for Nova Scotia and Fujian with area with different slopes

Slope (%)	**Nova Scotia**	**Fujian**
0.0 – 7.0	0.27	0.31
7.0 – 11.3	0.30	0.34
11.3 – 17.6	0.40	0.45
17.6 – 26.8	0.45	0.51
> 26.9	0.50	0.57

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