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Valuation and validation of carbon sources and sinks through land cover/use change analysis: The case of Bangkok metropolitan area

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ABSTRACT

This study investigates carbon sources and carbon sink estimation, nexus and validation through Land cover/land use (LCLU) change analysis of Bangkok Metropolitan Area (BMA), Thailand. Considering spiking population and carbon emission trends, especially in metropolitan cities of developing countries, such estimations are direly needed. Moreover, quantification and empirical evidence involving such a multidisciplinary analysis are rarely available. Therefore, this study would help in understanding the relationship among economic development, carbon emissions, carbon sinks and land use change in BMA. CO_2 emission and sequestration data from 1987 to 2015 were collected, and the changes and rate of change in LCLU were assessed by analyzing landsat satellite images of 1987, 1995, 2005, and 2015. Best efforts were put to attain net gains and losses in carbon sources and sinks analyses. Results showed that carbon sources have increased by almost 4-folds from 1987 to 2015 while sinks have declined rapidly to half of its original amount since 1987. The gap between carbon sources and sinks is widening year by year and will, if it continues in this manner, cover up the whole green space of BMA in the next decade. The LCLU change results also verified and showed the same results, which helped in validating such outcomes. Urban/built up area sprawl over 60% of BMA's area while the remaining 40% constitutes agricultural land, green spaces, and water bodies. Furthermore, the rate of change of urban area was 157.4 sq km during 2005–2015 and 218 sq km during 1995–2005. Therefore, policy makers of BMA should seriously draft expansion plans of green spaces and public parks and implement it immediately to tackle with carbon emissions and land use change disquiets. Meanwhile, awareness regarding conservation of green areas, trees, and use of public transport could be another set of bottom-up policies.

1. Introduction

Bangkok is a world-famous tourist destination due to its multiple attractions and natural diversity. Bangkok is the capital of Thailand, and its rich history, culture, and heritage dates back to the early fifteen century when it was a village near the Chao Phraya River. In the modern world, Bangkok (also known as Krung Thep Maha Nakhon or Krung Thep) is referred to in three different ways: Bangkok, Bangkok Metropolitan Area (BMA), and Bangkok Metropolitan Region (BMR). These names are distinguished on the basis of official government-defined boundaries. The redefined boundaries are due to expansion in the main city of Bangkok and the resulting population, industrial, and commercial pressures. Thailand's only metropolitan city, Bangkok, is facing huge population pressure and other challenges. Bangkok's population has increased from 4.7 million in 1980 to more than 10 million in 2016 (Permpool et al., 2016).

While there is no solution for the increasing population pressure and density in any metropolitan city except efficient-resource management. The BMA is a mixed-clustering city of big economic sectors, such as transport, domestic, and power generation industries. The total greenhouse gas (GHG) emissions of Thailand have increased from 170.7 million tons of carbon dioxide equivalent ($MtCO_2e$) in 1990 (Sinthunawa, 2009) to 401.71 $MtCO_2e$ in 2015 (WRI, 2016). Likewise, Thailand's energy use has increased from 41,944 kilotons of oil equivalent (ktoe) in 1990 (Sinthunawa, 2009) to 179,147 ktoe in 2015 (WRI, 2016). Despite all such economic developments, a balanced urban ecosystem requires a mix of green spaces and architecture alongwith smart urban planning in order to avoid urban sprawl. BMA is lacking green spaces and dissimilarly rapid growth in urbanization is making the city vulnerable in the context of occupying natural environment (Wang et al., 2016). BMA is among those capital cities occupying least green spaces and least area per person ($3m^2$) as well. In

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this scenario, understanding the relationship between urbanization and the declining green environment becomes immensely important. Since 1960, Bangkok has faced many environmental challenges (MacGee and Robinson, 1995) such as urban sprawl (Hara et al., 2005) and occupying recreational spaces (Goldburg, 2003), and this unmanaged expansion has resulted in insufficient infrastructure (Kunvitaya and Dhakal, 2016). In the BMA, green spaces, sparse vegetation, and urban sprawl are serious environmental problems distinct from energy use and carbon emissions, which are another set of indicators that need to be countered.

A well-researched issue in cities is the nexus of carbon sources and carbon sinks, which describes the actual situation of gains and losses (Ali and Abbas, 2013). However, it is not that easy to estimate these correctly and then rely on the findings using one method or technique. Carbon sources are increasing due to expansion and urbanization processes, and carbon sinks are declining according to the general perception. However, factual and empirical evidence is largely lacking in this field. No exact estimation or validation of carbon sources and sinks is available for various metropolitan cities, especially for the BMA. Several researchers studied numerous aspects of carbon emissions and green vegetation in different countries and cities (e.g., Ali and Abbas, 2013; Andersen et al., 2010; Avignon et al., 2010; Cai et al., 2008; Chen and Zhang, 2010; Cohen, 2012; Dhakal, 2009; Kennedy et al., 2010; Liu and Shi, 2017; Mateo-babiano, 2012; Permpool et al., 2016; Phdungslip, 2009; Quadrelli and Peterson, 2007; Selvakkumaran et al., 2014; Shrestha and Rajbhandari, 2010; Yang et al., 2009). However, such studies overlooked the analysis and discussion of CO_2 sinks, which are an important pillar for estimating net CO_2 emissions. CO_2 emissions simply cannot be declared as the total CO_2 emission unless the amount is subtracted from CO_2 sinks.

Likewise, some studies (such as Birant, 2011; Bryan et al., 2010; Kamal, 2014; Wu and Jackson, 2016) have considered carbon sequestration, energy use, and mitigation options in different regions of the world, but they did not include the CO_2 sequestration factor. It is very rare to focus on the remote sensing techniques used in carbon sources and sinks estimation of metropolitan cities. Another use of remote sensing technique, a multidisciplinary approach, is to compare carbon emissions and sinks (urban vegetation) in a smarter way. None of the studies have verified the existence of carbon emissions and carbon sinks in Bangkok city. Ali and Nitivattananon (2012), Ali et al. (2013) and Yang et al. (2009) have conducted research on such issues but in different metropolitan cities. Thus, this research gap motivated us to conduct such a study in Bangkok Metropolitan Area. The main objective of this study is to investigate the carbon sources and sinks and validate them through land cover/land use change analysis in BMA. This study also answers a few research questions. How did the historical changes in land use occur in the metropolitan city? What is the effect of urban sprawl on the land use change in this area? How green spaces and built-up areas have grown or got destroyed from the past to present?

2. Research methods

The main objective of this research is to investigate carbon sources and carbon sink estimation, nexus and validation through land cover/land use (LCLU) change analysis of BMA. There are number of processes and parameters needed for this detailed estimation of annual carbon emission, carbon stocks or carbon sequestration in each of the carbon pools. Moreover, LCLU change analysis required comprehensive surveys, data and modelling. Therefore, multiple estimations and analyses are made through different methods/tools which are explained in the following sections step by step.

2.1. Study area

Bangkok Metropolitan Area is selcted as study area. BMA is capital city of Thailand. A historical city covering a huge population of more than 8 million and the largest hub of transportation, commercialization, services and tourism in Thailand. The total area of Bangkok is almost 1500 km^2 including one of the famous rivers (Chao Phraya river) of Southeast Asia (Kamal, 2014). Being rapidly urbanized city, Bangkok Metropolitan Area will be selected as the study area for this research. BMA lies on the 13.7° latitude and 100.6° longitude in decimal degrees with average 34 °C and 25.25 °C temperatures maximum and minimun, respectively. BMA is comprised of almost 50 amphoe (districts) and 169 tambons (sub-districts) (Sinthunawa, 2009). Fig. 1 shows the study area map.

2.2. Data used

We used both primary and secondary data for various purposes. The data analyzed comprised of CO_2 emission data from 1987 to 2015 of the major economic sectors of BMA, particularly industries, power generation, transportation, and all other sectors contributing to the economic growth. Moreover, CO_2 emission data of different energy types during the same time period for BMA was also collected. Furthermore, secondary data included topographical maps, meteorological data, profile studies, landsat satellite images, and land use distributions. Collection of primary data was performed in response to the requirements of remote sensing tools, a process technically called ground truth, in the form of field survey in order to confirm the locations of different places in the study area. The following factors were considered for the source of the satellite data: (i) availability of long time series of imagery for the study area, and (ii) less than 20% of cloud cover, witnessed in the dry season, especially in the months of January, February, April, and June, which are considered as less rainy and less cloudy months in Bangkok. With these two criteria, four landsat satellite images of BMA between 1987 and 2015 were acquired (Table 1). Since Landsat data that fulfills the requirements of the study for 1985 was not available, the image of 1987 was used. Ground reference data was obtained from the land survey using hand held Geographical Positioning System (GPS), and the reference data collected corresponded to five main LCLU classes. For carbon sequestration estimations, data of green spaces were collected from Tourism Authority of Thailand and Intergovernmental Panel on Climate Change (IPCC) sequestration factors was used. Major data sources included Energy Policy and Planning Office of Thailand; Intergovernmental Panel on Climate Change; Tourism Authority of Thailand; National Statistics Office of Thailand; and United States Geological Survey (USGS), etc.

2.3. Methodology

In order to achieve the objective of the study different methods and approaches were used. For carbon emissions and carbon sequestration analyses, statistical and carbon sequestration factors were utilized suggested by IPCC (2006).

2.3.1. Carbon sources and carbon sequestration

For CO_2 emission, four economic sectors, i.e., power generation, industry, transport, and other sectors were selected. In addition, four major energy sources abundantly used in BMA such as oil, natural gas, and coal/lignite were deliberated. In the estimate, we selected only CO_2 gas among the greenhouse gases (GHGs), it being the major gas emitted in the country as well as in BMA. To estimate the net CO_2 emissions, calculation of carbon sinks in this study focused on the change of green areas (parks, play grounds, golf clubs, etc.) and sparse trees throughout the study area. Annual level of carbon sinks from the green areas and trees are calculated through Eq. (1).

$$CO_{2sink} = (A_{trees} \times S_{trees}) + (A_{greenparks} \times S_{greenparks}) \quad (1)$$

Where CO_{2sink} is annual carbon sinks from the trees (ton of CO_2); A_{trees} is Area of trees in the calculated year (sq km); S_{trees} represents CO_2