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Land use changes and soil redistribution estimation using ^{137}Cs in the tropical Bera Lake catchment, Malaysia

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ABSTRACT

The catchment of Bera Lake in Pahang State, Peninsular Malaysia has experienced severe land use changes since 1972 with some 340 km^2 (out of a total area of ~600 km^2) having been converted to oil palm and rubber plantations and in some places, newly cleared for monoculture. The proportional model using the ^{137}Cs radionuclide was recognized as being the most suitable conversion model for estimating soil redistribution in the catchment as the deforested land has been cultivated once in a medium-term range of 30–40 years. Thirty-five bulk core soil samples were taken to a depth of 25 cm in areas of different land use and known dates of tillage commencement in the catchment. Ten bulk core samples were also collected in the bottom sediments of wetlands and open waters to estimate accumulation rates in these sink areas. Individual land development districts with known elapsed times from start of tillage allowed determination of soil redistribution rates and preparation of a soil redistribution map. A mean soil erosion rate of 915 ± 345 t h^{-1} y^{-1} was determined in areas of cleared land, whereas rates of 117 ± 36, and 70 ± 35 t h^{-1} y^{-1}, were determined in areas of developing, and developed, oil palm and rubber plantations, respectively. The overall accumulation rate of eroded soils within the wetlands and open waters was determined to be 1.025 cm y^{-1} since 1995. The Bera Lake catchment soil redistribution map is the first attempt in Malaysia to map soil redistribution using the ^{137}Cs technique on a catchment scale. The soil redistribution map will provide good guidelines for future soil conservation practices and sustainable land use programs.

1. Introduction

Land use changes including deforestation and land clearing are playing an important role in soil degradation and soil loss in catchment areas throughout the world. There is also a long history on the application of on-ground erosion plot experiments and fallout ^{137}Cs and ^{210}Pb to estimate soil redistribution (Walling, 1999). Cesium ^{137}Cs is a fission product and atomic bomb-derived radioisotope that has a half-life of 30.02 years and emits gamma rays with an energy of 661.6 keV (Poreba, 2006). This radionuclide was first applied by Yamagata et al. (1963) and Rogowski and Tamura (1970) to estimate rates of soil erosion. Analytical methods and models for estimating soil erosion using ^{137}Cs have remarkably improved over the last four decades. Ritchie (2005) has stated that published papers on the ^{137}Cs technique started in 1961 and reached a maximum number in 1999. New models for estimating soil erosion have also been introduced by IAEA (1995, 1998), Rogowski and Tamura (1970), Walling and Quine (1990), Walling and He (1999), Walling et al. (1999), Zapata and Garcia (2000), and Poreba (2006). Mabit et al. (2008a) have evaluated the different models and noted the advantages and limitations of using ^{137}Cs and ^{210}Pb for assessing soil erosion. The ^{137}Cs technique is the only technique that can be applied both quickly and efficiently to measurements of soil loss and redeposition (Ritchie, 2005). A PC-compatible software package by Walling et al. (1999) contains an improved model that is based on a number of other models and is applicable to both cultivated and non-cultivated areas and can include contributions from fallout radionuclides ^{210}Pb and ^{7}Be. The

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said software comprehensively runs the Proportional Model, the Mass Balance I, II, and III Models, the Profile Distribution Model and the Diffusion and Migration Model. Specific requirements are, however, needed in applying the models in terms of the underlying assumptions, descriptions and representation of temporal variation (Walling et al., 1999).

Studies on the Bera Lake catchment and its open water started in 1961 due to its scientific, anthropological and agricultural importance. Biological features of the catchment have been studied by Merton (1962), Furtado and Mori, 1982, Ikusima and Furtado, 1982, and Giesen (1998), while its palynological history and anthropological aspects have been investigated by Morley (1981), and Surut (1988), respectively. The geological setting and evolution of the Bera Lake basin has been presented in Hutchison and Tan (2009), whilst peat accumulation and more recent palynological aspects were studied by Phillips and Bustin (1998), Wust and Bustin (1999), Wüst and Bustin (2001), and Wüst et al. (2002).

A literature review indicated that the ^{137}Cs technique has never been applied to estimating soil redistribution patterns in the Bera Lake catchment even though there have been severe land use changes over the past few decades. The objective of this research was therefore, determination of the soil redistribution pattern as a result of land use changes within the Bera Lake catchment using the ^{137}Cs fallout technique. The capability of application of the ^{137}Cs method toward soil redistribution mapping in a humid tropical catchment was also another objective of the research.

1.1. Study area

Bera Lake catchment (BLC) is located in the central part of Peninsular Malaysia, between 2°, 53′, 00″–3°, 10′, 00″N and 102°, 30′, 30″–102°, 47′, 00″E (Fig. 1). The catchment covers an area of some 600 km^2 and was covered by primary rainforest, though five Federal Land Development Authority (FELDA) schemes from 1970 to 1995, have led to 292.86 km^2 of the original forest being converted to oil palm and rubber plantations (Henson, 1994; MPOC, 2007). The BLC was designated under the Convention of Wetlands as the first RAMSAR Site in Malaysia in 1994 with the FELDA districts being called Buffer Zones. Soil conservation management practices, however, have never really been applied within these Buffer Zones, both before, and after, establishment of the RAMSAR Site. A map showing recent land use in the Bera Lake catchment, prepared using the geographical information system (GIS) technique and a satellite image (Spot 5, 2009) of spatial resolution 10 m furthermore, shows that there has been is continued agricultural development and encroachment into the RAMSAR Site with new oil palm and rubber plantations (Fig. 2). Cleared land has also increased some 47.14 km^2 in area since 1994; reaching a maximum area of 340 km^2 in 2009. The remaining area is covered by wetlands and pristine lowland rain forests (forest and reed swamps). The catchment is located between the eastern and western mountain ranges of the Peninsula with the highest hills being up to 140 m above sea level (Wüst and Bustin, 2004). A digital elevation model (DEM), developed to prepare a slope map of the catchment, shows that up to 50% of the area comprises low lands where the slope varies between 0° and 4°.

The Bera Lake catchment was segregated into 12 hydrological subcatchments with open water located in the northernmost part in subcatchment 3 (Fig. 1). The overall flow of streams is northwards with subcatchments 4–12 draining into the south end of Bera Lake. Two other streams from subcatchments 1 (Kelangton stream), and 2, drain into the middle, and northern parts, of the Lake, respectively. Bera Lake drains through an outlet stream in its northern most part into the Bera River which flows northwards into the Pahang River.

The study area has a humid tropical climate with two monsoon periods. Heavy rainfall is received during the Northeast (November to March), and Southwest (June to August), Monsoons, whist there is less rain in April and May and in September and October. The mean annual temperature is about 30 °C and ranges from 25 °C to 38 °C (Chee and Abdulla, 1998). Rainfall records from 1970 to 2009 at the Fort Iskandar Station, which is located at the mid-point of the Bera Lake catchment, show that minimum, and maximum, annual rainfall are 1000, and 2602, mm respectively. Field observations and laboratory analyses show the soils of the BLC to be Ferralsols; the

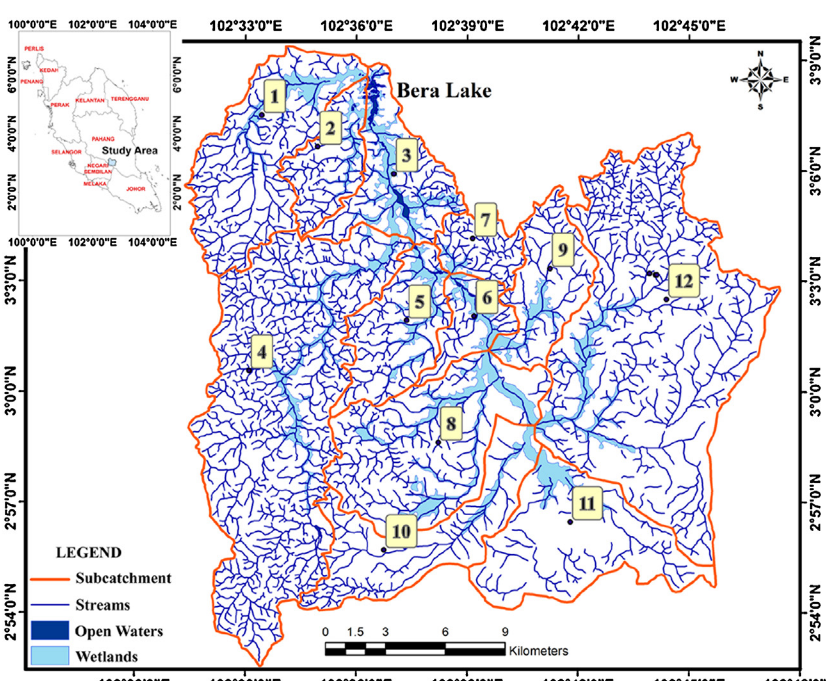

Fig. 1. Geographic position of Bera Lake catchment, subcatchments, and stream pattern.