DEVELOPING AN INTEGRATED CATCHMENT MANAGEMENT THROUGH WATER QUALITY ASSESSMENT, LANDUSE CHANGES ANALYSIS, SOIL EROSION STUDY & COMMUNITY ENGAGEMENT IN BERTAM RIVER CATCHMENT, CAMERON HIGHLANDS, MALAYSIA

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Doctor of Philosophy
(ENVIRONMENTAL MANAGEMENT)

UNIVERSITI MALAYSIA PAHANG
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We hereby declare that we have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Environmental Management

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Thesis submitted in fulfillment of the requirements for the award of the degree of Doctor of Philosophy (Environmental Management)

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ABSTRAK

ABSTRACT

The rapid boost in construction and agro-tourism activities has significantly threatened the water quality within Bertam River Catchment, Cameron Highlands (BRCC) in Malaysia during the last two decades. The scenario has drawn the attention to investigate the relationship between land use and water quality for the sustainable development of BRCC. Hence, the current research aims at developing an effective model for the sustainable management of BRCC using integrated assessment of scientific findings with quantitative social information. Scientific assessment was carried out to determine the spatio-temporal variations of water quality, to assess the landuse changes and their impacts on water quality, as well as to estimate the spatial distribution of soil erosion under different landuses. To investigate water quality, samples were collected six times from January 2014 to February 2015 from twelve preselected stations. A total of fourteen water quality parameters were analyzed. For landuse study, four-time series landuse maps (1984, 1997, 2004 and 2010) were used to analyze the land pattern changes by change detection technique using GIS approach. The revised universal soil loss equation (RUSLE) model was applied to estimate the soil erosion rate. A community based survey was also conducted using a well-structured questionnaire. The results of water quality assessment showed significant temporal and spatial differences ($p<0.05$) in most of the water quality parameters across the catchment. The average concentrations of total suspended solids, turbidity, biochemical oxygen demand, ammonical-nitrogen, and phosphate-phosphorous exceeded the Malaysian National Water Quality Standards (NWQS) level for IIB. Nutrients, organic matter, and suspended sediments were determined as the major pollutants. The overall water quality status of the BRCC is classified as “Slightly Polluted” and falls under class III category according to the DOE-WQI. The landuse study revealed that landuse changes were mainly characterized by the expansion of agricultural ($16.37$ km$^2$) and urban ($4.15$ km$^2$) land types, reducing the forest ($22.85$ km$^2$). A noticeable change in the agricultural activities was observed along the higher slope ranges (>20°) with the passage of time. The urban and agricultural landuses are mainly related to water quality deterioration, where the forest is associated with better water quality within BRCC. The results of soil erosion assessment indicated that the annual average soil loss rate of the catchment was predicted to be $123.23$ ton/ ha/ year. Individually, the average rate for Upper, Middle and Lower sub-catchment was $27.60$, $31.80$ and $63.83$ ton/ ha/ year respectively. Agricultural activities were the main contributor to higher soil erosion in different sub-catchments. The topography of the catchment also played a major role in controlling soil movement. Community-based survey findings showed that the people have good knowledge and perception of the catchment environment. Therefore, significant associations were observed between the scientific findings and communities’ observations. Considering all the social and scientific findings, the proposed integrated model for BRCC management suggest that the authorities should provide the scientific information through internet and organizing workshops to motivate and create awareness. Similarly, whenever they take any initiative for management program within BRCC considering the scientific findings, they should focus more on the aged, higher educated and older residents for their higher level of awareness and positive willingness for participation. Overall, the findings of this study suggest that the effective implementation of socio-scientific integrated approach by the authorities can be an innovative initiative towards the development of sustainable catchment management.
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REFERENCES


Doe, W., Jones, D., & Warren, S. (1999). The soil erosion model guide for military land mangers: Analysis of erosion models for natural and cultural resources applications. *US Army Engineer Waterways Experiment Station Tech. Rept. ITL.*


Fortuin, R. (2006). Soil erosion in Cameron Highlands: An erosion rate study in a highland area. Saxion University, Deventer, the Netherlands, Regional Environmental Awareness Cameron Highlands, 1-83.


Kang, N., Sakamoto, T., Imanishi, J., Fukamachi, K., Shibata, S., & Morimoto, Y. (2013). Characterizing the historical changes in land use and landscape spatial pattern on the oguraike floodplain after the Meiji Period.


