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Physical resources assessment in a semi-arid watershed: An integrated methodology for sustainable land use planning

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ABSTRACT

The study demonstrates the application of geospatial technologies to evaluate physical resources of semi-arid watersheds and presents a comprehensive methodology applicable elsewhere. The selected Andipatti watershed, located in Theni district in the State of Tamil Nadu (India), is known for agricultural activities; however, haphazard planning, management practices and inadequate investments result in land and water resource degradation. Since most of the agricultural lands in developing countries are similar to these conditions, the present study is attempted as a case to develop a framework to assess the land and water resources potential, utilisation level and land suitability for agriculture; and to evolve better management strategies. The physical characteristics of the watershed were studied based on in-situ, remotely sensed and secondary data sources. Thematic layers were generated with the combination of remote sensing, image processing and GIS techniques. In order to characterize and quantify the watershed based on soil erosion and surface runoff rates, the revised universal soil loss equation (RUSLE) and natural resources conservation services curve number (NRCS-CN) were utilized. Data on water levels and geochemistry of water samples, collected from 36 dug wells were also utilized for this study. Sodium adsorption ratio (SAR) and electrical conductivity, as formulated by the US Salinity Laboratory (USSL) were utilized to examine the suitability of groundwater for irrigation purpose. The storie index has been used to assess the productivity of land using profile and textural characteristics of the soil. Keeping Food and Agricultural Organisation (FAO) guidelines as a reference, as many as 727 homogenous micro-land units were prepared. The physical land qualities and characteristics of each land unit were compared with the requirements of 13 major crops of the study area and suitable crops for each unit were identified. The individual suitability classes of all crops were compared using logical analysis and suitability crops for each land unit were determined under irrigated and rain-fed conditions. In order to integrate the results of these analyses and to suggest sustainable agricultural development measures, the study area was divided into 44 micro-watersheds. The information on land productivity, groundwater quality and existing land use/land cover patterns of the watershed were used to calculate land potential-utilisation index and groundwater potential-utilisation ratio for all micro-watersheds. All the results of land and water resources assessment were compared and a proposed land use map was prepared. The findings suggest strategies for coping with sustainable agricultural practices for the present study area and provide an integrated methodology for future assessments elsewhere, especially in the developing countries.

1. Introduction

Land and water are the basic natural resources on which the existence of humankind depends. In all aspects of land use planning, it is necessary to study the potentials, problems, utilisation levels and suitability of land and water resources for various uses (Verburg et al., 2004; Margules and Pressey, 2000). The United Nations (UN) has set a goal (Goal No.2; Sustainable Development Goals of UN) to end hunger, achieve food security and improved nutrition through sustainable agriculture by the year 2030. In order to realize this goal, profound changes in land use, especially in agriculture, to ensure sustainable food production and enhance incomes of small-scale food producers are necessary (UN, 2015). Since the watershed is considered as a more efficient and appropriate unit for land use planning and implementation for natural

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resource management programmes, the watershed-based approach will be helpful for optimizing the current land use practices (Saadat et al., 2011). Presently, most of the watershed-based models are applied independently to study various components of hydrological and land use systems (Hernandez et al., 2000; Santillan et al., 2010; Pan and Wen, 2014; Tang et al., 2015; Mohammad and Adamowski, 2015; Pandey et al., 2016). Contrary to the isolated and incoherent attempts, a watershed-based integrated approach may help prevent soil erosion, recharge groundwater and increase in agricultural production (Kushwaha et al., 2010). Similarly, rather than being subjective, the integrated approach should be more of quantitative and inclusive of models in a single framework for developing an operational approach. In addition, due consideration and inclusion of quantitative or semi-quantitative models to develop an integrated framework (Babbar-Sebens et al., 2015; Mallampalli et al., 2016) need to be attempted.

Since soil erosion and surface runoff rates are the base for watershed hydrology, a thorough understanding of their spatial distribution is a prerequisite to develop rational land use plans (Santillan et al., 2010; Nagaraju et al., 2011). An accurate determination of soil erosion and surface runoff is essential to address soil and water conservation practices in a watershed (Rao et al., 2010; Balasubramani et al., 2015). Both the rates act as good indicators of health and function of a watershed (Hernandez et al., 2000). The adverse impacts of severe soil erosion and excessive surface runoff on hydrological systems have long been recognized. However, estimation of soil erosion and surface runoff is often difficult, especially in the developing countries, due to the complex interplay of many factors, including, but not limited to, the topography, climate, land use/land cover (LU/LC), soil and anthropogenic activities and paucity of monitored data on these factors.

A longtime research in estimation of soil erosion leads to the development of many quantitative models, but in practice, the revised universal soil loss equation (RUSLE) is most widely used in predicting soil erosion loss (Angima et al., 2003; Shi et al., 2004; Kumara et al., 2006; Renard et al., 2011; Ranzi et al., 2012). An increased use of RUSLE models significantly improved the erosion assessment process that can be applied to both monitoring and modelling the effects of land use on soil erosion potential (Mati et al., 2000; Wang et al., 2017). Similarly, the most commonly used method for estimating surface runoff in an ungauged watershed relies on runoff curve numbers developed by the Natural Resources Conservation Services (USDA, 1986; Mishra et al., 2004; Yuan et al., 2014).

Improving agricultural production is one of the foremost scientific challenges for the next decades (Löw et al., 2017). Any land use recommendation without giving due consideration to soil resources and their constraints may not help to achieve the goal of sustainable agricultural production (Sehgal, 2012). Many attempts were made by researchers to study the suitability of land and water for various uses. Initially, these kinds of suitability studies were qualitative in nature while quantitative aspects gained importance afterward (Singh, 2012). In this context, Food and Agricultural Organisation (FAO) methodology on land suitability evaluation play an important role in increasing agricultural production of a region (Mansor et al., 2012; Feizizadeh and Blaschke, 2013). In addition to suitability evaluation, an assessment of optimum utilisation of the available land resources is a prerequisite to achieving a sustainable agricultural production (Perveen et al., 2007) whereas, identification of gaps between potential and utilization level is a critical element in any land use planning and management strategy.

In recent years, it has been recognized that the quality of water has greater importance than the quantity of water (Cook and Bakker, 2012). Therefore, a chemical analysis is necessary to assess the groundwater, which is essential in determining its usefulness in irrigation system (Mohanty and Behera, 2010; Atzberger, 2013). Suitability analysis of groundwater for irrigation purposes is also necessary for suggesting optimal planning measures (Sophocleous and Perkins, 2000) because the groundwater is being increasingly used for agricultural production in semi-arid regions (VanderPost and McFarlane, 2007). Groundwater suitability for irrigation of agricultural crops can be assessed in many ways and it can be easily achieved in terms of assessing salinity and sodicity (USSL, 1954).

Traditionally, these kinds of assessment are carried out mainly using topographical maps and limited field surveys (Shrimali et al., 2001; Lal et al., 2003). The methodology adopted for data collection, thematic layer preparation and spatial analysis is largely based on the sampling design and knowledge of subject experts. However, the advent of remote sensing and GIS overturned the assessment of watershed resources and simplified the complex steps in integrating the results (Mohanty and Behera, 2010). The geospatial technologies are now widely used in resources monitoring and estimation of hydrologic variables such as surface runoff and soil erosion (Patila et al., 2008; Da Silva et al., 2013; Vagen et al., 2013; Aquino Da Silva et al., 2015; Liu et al., 2016). Many remote sensing based methods used for resource assessment can be readily applied to various models (Tsendbazar et al., 2015; Chen et al., 2017).

Notwithstanding the merits of resources assessments reported in many published research works, application of integrated assessments is scarce. Even if few studies have attempted, there is a paucity of comparison between different model results, which thwarted so far, establishment of unique, yet effective modelling, and model assessment methodology. With this background, the present study attempts to prepare a comprehensive framework for the assessment of land and water resources of a semi-arid Andipatti watershed in a bid to pursue the objective of land use planning and sustainable development of agriculture.

2. Choice of the study area

The Andipatti watershed, located in Theni district in the State of Tamil Nadu, South India is known for agricultural activities. As shown in Fig. 1, it sprawls between the latitudes of 9°49′33″ and 10°2′57″ North and longitudes 77°31′47″ and 77°39′20″ East and covers an area of about 250 sq.km. About 65 percent area of the watershed is utilised for agricultural practice. Among 16,514 land-holders in the study area, the marginal farmers (holding less than one hectare of land) account for 63 percent and most of the rest, 23 percent are small farmers (1–2 ha). Even though the watershed falls under semi-arid climate with an annual average rainfall of 790 mm, about 40 percent of the watershed area is under irrigated agriculture (~100 sq.km). To earn an income for day-to-day expenses and socio-economic development, most of the farmers follow intensive crop production and thereby over-exploit the basic natural resources. Due to the absence of adequate investments and appropriate management practices, the intensive crop production in this region creates the acutest problem of land and water resources degradation. These paradigms allowed selection of the Andipatti watershed as a test case to understand the resources potential, assessment of utilisation level and suitability of land and water for agriculture with which better management strategies can be emulated and implemented.

3. Materials

The physical characteristics of the watershed were studied based on in-situ, remotely sensed and secondary data sources.