Geoscience Frontiers 7 (2016) 115–124

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Geoscience Frontiers

journal homepage: www.elsevier.com/locate/gsf

Research paper

An approach to delineate groundwater recharge potential sites in Ambalantota, Sri Lanka using GIS techniques

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A R T I C L E   I N F O

Article history:
Received 2 October 2014
Received in revised form
11 February 2015
Accepted 13 March 2015
Available online 4 April 2015

Keywords:
GIS
Groundwater recharge
Water management
Weighted overlay
Sri Lanka

A B S T R A C T

The demand for fresh water in Hambantota District, Sri Lanka is rapidly increasing with the enormous amount of ongoing development projects in the region. Nevertheless, the district experiences periodic water stress conditions due to seasonal precipitation patterns and scarcity of surface water resources. Therefore, management of available groundwater resources is critical, to fulfil potable water requirements in the area. However, exploitation of groundwater should be carried out together with artificial recharging in order to maintain the long term sustainability of water resources. In this study, a GIS approach was used to delineate potential artificial recharge sites in Ambalantota area within Hambantota. Influential thematic layers such as rainfall, lineament, slope, drainage, land use/land cover, lithology, geomorphology and soil characteristics were integrated by using a weighted linear combination method. Results of the study reveal high to moderate groundwater recharge potential in approximately 49% of Ambalantota area.

1. Introduction

Groundwater accounts for about 30% of the earth's freshwater, whereas surface water resources from lakes and rivers accounts for less than 0.3% (Shiklomanov, 1993). Demand for fresh water resources in the world is noticeably increasing as a result of rapid industrialization and population growth. Hence, groundwater extraction has become an integral part in many of the water management approaches, especially for rural areas. Sri Lanka has been traditionally divided into 3 climatic zones namely, wet, intermediate and dry zone based on average annual rainfall. The wet zone receives over 2500 mm, the intermediate zone receives between 1750 and 2500 mm and the dry zone receives less than 1750 mm of average annual rainfall. The dry zone extends over two thirds of the island covering the northwestern, north-central, northern, northeastern, eastern and southeastern regions of the country (Zubair, 2002; Senanayake et al., 2012). The dry zone periodically experiences drought conditions due to variations in rainfall, high evaporation rates and unique soil conditions. Thus, scarcity and inaccessibility to the surface water resources cause inhabitants to exploit groundwater for their domestic, agricultural and industrial uses.

Groundwater table depletes when pumping rates are higher than the rate of replenishment. Hence, areas with excessive groundwater withdrawal rates experience a significant volume decrease in the groundwater reservoirs. This can cause depletion of water levels in wells, streams and lakes, deterioration of water quality, land subsidence and higher pumping costs (Sophocleous, 2002; Wada et al., 2010).

Artificial recharge is a type of controlled recharge where surface water is put on or in the ground for infiltration and subsequent movement to the aquifer to augment the groundwater resources. It can be defined as the practice of increasing the amount of water entering to the subsurface reservoirs by artificial means (Bouwer, 2002; Bhattacharya, 2010). However, locating the potential sites for artificial recharge is very difficult and depends on many interdependent factors including rainfall, drainage density, lineament density, slope, soil permeability, land use/land cover, geology and geomorphology.

The influence of different factors on the artificial recharge process is varied. Rainfall can be identified as one of the triggering factors of artificial recharging, as an excessive amount of surface water is stored and recharged during rainy seasons. Drainage

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Peer-review under responsibility of China University of Geosciences (Beijing).

http://dx.doi.org/10.1016/j.gsf.2015.03.002
1674-9871/

density is another highly influential factor in identifying suitable artificial recharge sites. The presence of a natural drainage system is an indirect indication of the high permeability and porosity of the terrain due to its relationship with surface runoff (Krishnamurthy et al., 2000). Most of the geological discontinuities are attributed to faults or fracture systems, which act as conduits for groundwater movement and storage. Therefore, lineament density can be used to infer high secondary porosity in a particular area of interest. In general, a buffer zone of 300 m around each lineament is considered a favourable zone for groundwater recharge (Krishnamurthy et al., 2000). The slope gradient directly influences the infiltration of surface water. Low levels of recharging can be observed on steep slopes as water flows rapidly downwards providing insufficient time to infiltrate. On the other hand, flat lands facilitate groundwater recharging due to extensive retention of rain water, providing moderate evaporation conditions. Coefficient of soil permeability is one of the governing factors for determining the best sites for constructing artificial recharge structures (Eid et al., 2006; Elbeih, 2007). Generally, permeability is directly proportional to the effective porosity of the soil. Grain size, shape, structural arrangement and stratification of grains, properties of the pore fluid, voids ratio, entrapped air (degree of saturation) and other foreign matter and adsorbed water in clayey soils can be identified as the most influential factors to the permeability of soils (Punmia et al., 2005). Accordingly, soils consist of gravels and coarse sand exhibits high permeability levels, while fine sands and loam exhibit moderate permeability levels. Clay and silt typically show low permeability levels and impervious conditions (Saunders, 2001). Land use/land cover refers to vegetation, water bodies, homesteads, forests, etc. Land use/land cover influences the rate of surface runoff, infiltration and groundwater utilization. Therefore, land use/land cover can be considered as an indicator in the selection of sites for artificial recharge of groundwater. Geology provides descriptive information on underlying soil/rock layers and their properties. Porosity of rocks differs from one rock type to another. Effective porosity may be original or induced and governs the recharging capacity by providing space to retain water. Geomorphological features combined with structures and lithology controls the occurrence, movement and quality of groundwater. Evolution of landforms is useful to understand the occurrence of porous and permeable zones, Therefore, geomorphology of the study area is an essential component to be considered for groundwater recharging.

Geospatial technologies have become an important tool in water studies due to their capability in developing spatio-temporal information and effectiveness in spatial data analysis and prediction (Ghayoumian et al., 2007; Nagarajan and Singh, 2009; Subagunasekar and Sashikkumar, 2012). Various studies have been carried out throughout the world to identify the groundwater recharge potential zones by employing remote sensing and GIS techniques (Krishnamurthy et al., 2000; Sener et al., 2005; Shaban et al., 2006; Solomon and Quiel, 2006; Tweed et al., 2007; Yeh et al., 2009; Riad et al., 2011b). Most of these studies were based on knowledge-driven factor analysis, integrating different thematic layers such as land cover/land use, geology, geomorphology, lineament density, drainage density, slope, soil permeability, etc. with GIS techniques. Satellite remote sensing and image processing techniques were often employed in these studies for the preparation of necessary thematic layers. In addition, existing maps, data bases, aerial photographs and field data collection have been commonly used in factor layer preparation.

2. Study area

Based on the availability of surface water resources, Hambantota (Fig. 1) is considered as a region experiencing water stress conditions intermittently within the dry zone of Sri Lanka. Hambantota is a semi-arid region where dry weather with bright sunshine prevail, other than in western and northwestern parts of the district. The average annual temperature of the district ranges from 26 to over 30 °C. These climatic conditions facilitate high evaporation rates in the district. Annual rainfall of the region is mainly contributed by the monsoonal rains, especially by the north-east monsoon continuing from October to January. Paddy cultivation of the district takes place in two seasons namely 'Yala', from April to September, and 'Maha', from October to March, based on the annual rainfall pattern (Zubair, 2002). The district can be divided into 3 climatic zones based on the average annual precipitation namely, dry, intermediate and wet zones. Climatically dry areas of the district receive an average annual rainfall of about 1000–1250 mm, while intermediate parts receive rainfall varying from 1000 to 1500 mm. Wet regions of the district receive rainfall of about 1500–2000 mm (Hambantota District Secretariat, 2011). However, the amount of annual rainfall decreases from west towards eastern parts of the district based on the influence of monsoonal rains. Furthermore, during June to August and January to March most of the areas of Hambantota receive considerably low rainfall (Senanayake et al., 2013). Accordingly, water management plays an integral role of the economy of the inhabitants of the district since the main livelihood of Hambantota is agriculture.

The current infrastructure development projects in the district and the consequent increase in population will significantly increase the demand for fresh water. Implementation of a suitable water management system is essential to face the increased water demand. Groundwater recharge is a requisite to augment water resources and minimize the depletion of groundwater levels. Hence, identifying suitable groundwater recharging sites is a prerequisite in this endeavour.

Considering the high drainage density due to the existence of Walawe River, Ambalantota Divisional Secretariat of Hambantota District (Fig. 1) was selected as the area of interest in this study. Ambalantota is located between latitudes 6.08°N and 6.24°N and longitudes 80.89°E and 81.03°E covering 213 km^2 of land. The irrigation system of Ambalantota encompasses several rainwater harvesting reservoirs including the Ridiyagama reservoir which covers 3000 acres, the largest in the area. Since agriculture is the main livelihood of the inhabitants of the area, macro and micro irrigation systems play an important role in the economy of Ambalantota. Further, it is noteworthy that River Walawe reaches the ocean in the Wanduruppa area of Ambalantota. High drainage density in Ambalantota enables the region to be developed as a hub for future water management systems, specifically to serve Hambantota District. Ambalantota is located in the central part of the Hambantota District and is subjected to the same average climatic and geologic conditions.

3. Materials and methods

GIS techniques were employed in this study to delineate the groundwater recharge potential of Ambalantota divisional secretariat based on time and cost effectiveness. Identification of suitable sites for groundwater recharge was conducted through a knowledge-based factor analysis, using rainfall, lineament density, slope, drainage density, land use/land cover, lithology, geomorphology and soil type layers. The methodology followed in this study to delineate suitable sites for groundwater recharging has been illustrated in Fig. 2.

The Ambalantota area falls under the dry zone of the country based on the traditional classification of climatic zones in Sri Lanka. Average annual rainfall of Ambalantota area was calculated using monthly rainfall data of Hambantota District between 1992 and