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Research paper

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

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ABSTRACT

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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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

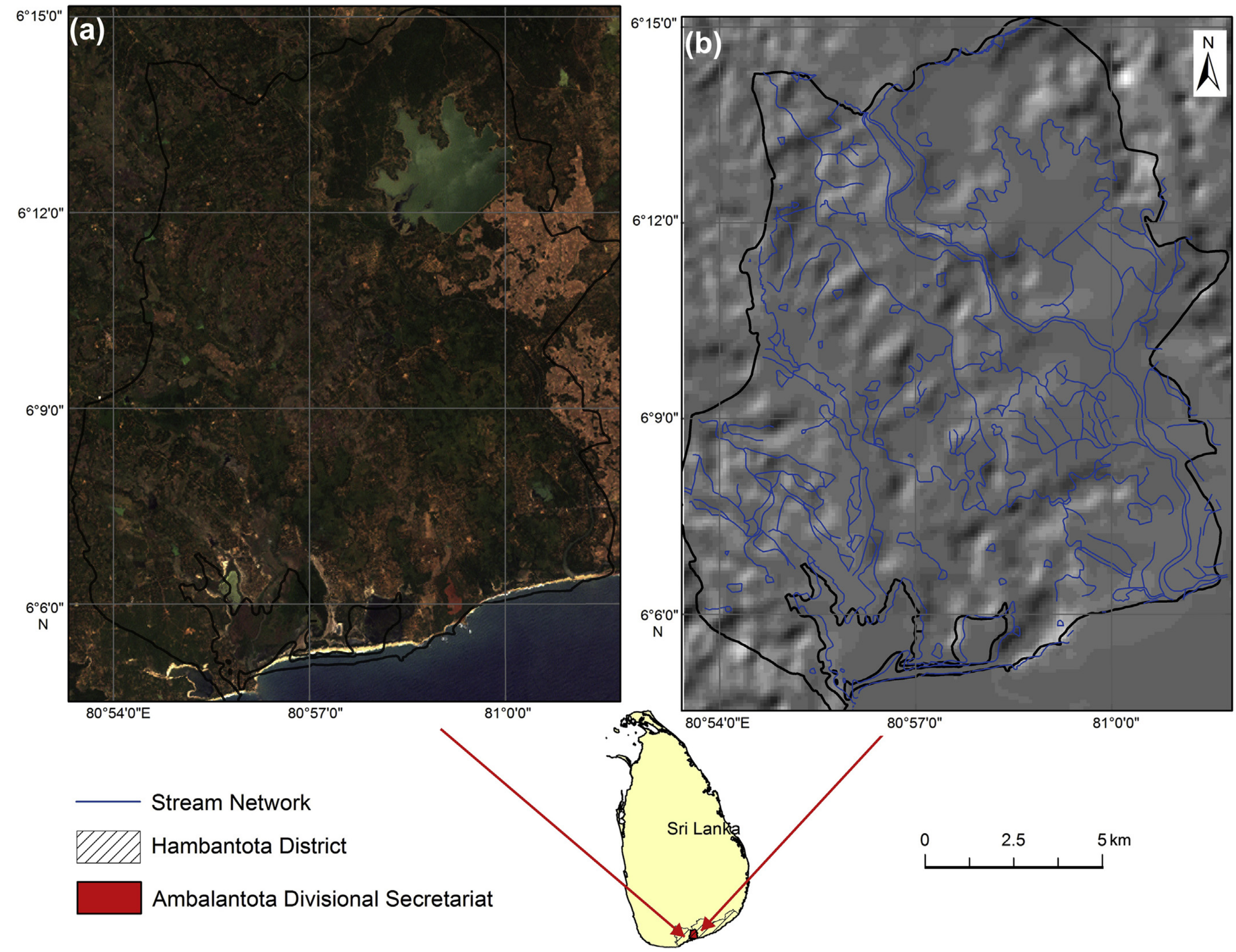

Figure 1. Location map of the study area, Ambalantota Divisional Secretariat, Hambantota District, Sri Lanka. (a) Landsat-8 natural colour composite of Ambalantota area; (b) terrain of Ambalantota area.

2012 collected from the Meteorological Department of Sri Lanka. Subsequently, an average annual rainfall map of Ambalantota (Fig. 3) was generated by employing interpolation techniques on a GIS platform. Annual precipitation of Ambalantota decreases from western parts towards eastern parts of the area.

The available 1:100,000 geology map of Sri Lanka prepared by the Geological Survey and Mines Bureau of Sri Lanka (2001) represents only the major lineaments in the area. Therefore, image processing techniques were employed to delineate other geological lineaments of the study area. A five metre interval contour dataset of Ambalantota prepared by the Survey Department of Sri Lanka (1999–2008) was employed in this endeavour. Firstly, contours were interpolated into a digital terrain model (DTM). Eight shaded relief images were subsequently generated corresponding to eight distinctive illumination directions, 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° using the DTM. Thereafter, those 8 images were compressed into 2 distinct layers. Lineaments in Ambalantota area were defined from the two resultant layers through automatic lineament extraction techniques (Weerasekara et al., 2014). Subsequently, manmade features were masked from the resultant layer. Thereafter, the developed lineament layer was merged with the lineaments in the geology map prepared by the Geological Survey and Mines Bureau of Sri Lanka. Finally, a lineament density map was prepared by using GIS techniques employing the resultant lineament layer (Fig. 4).

The obtained DTM of Ambalantota was further utilized to develop the slope map of the area using ArcGIS 10.1 software (Fig. 5). About 95% of the land area of Ambalantota is flat terrain characterized by slopes less than 2°, which facilitates slow runoff.

Drainage network layer (1:10,000) of the study area obtained from the Survey Department of Sri Lanka (1999/2000) was used to generate the drainage density map of Ambalantota (Fig. 6). Land use/land cover map of Ambalantota was developed using 14 1:10,000 digital map layers prepared by the Survey Department of Sri Lanka (1999–2008) (Fig. 7). About two third of the land area of Ambalantota is equally covered by paddy cultivation and home gardens. In addition, scrub and chena cultivations can be identified as other dominant land use classes in the area.

Lithological map of Ambalantota area was prepared by scanning, geo-rectifying and digitizing the 1:100,000 geology map produced by the Geological Survey and Mines Bureau of Sri Lanka (2001) (Fig. 8). Ambalantota area is underlain by metamorphic rocks such as garnet biotite gneisses, charnockitic gneisses, charnockitic biotite gneisses, hornblende biotite gneisses, alluvium, garnetiferous quartzofeldspathic gneisses, marble, hornblende gneisses, amphibolites, granite gneisses, quartzofeldspathic gneisses, etc.

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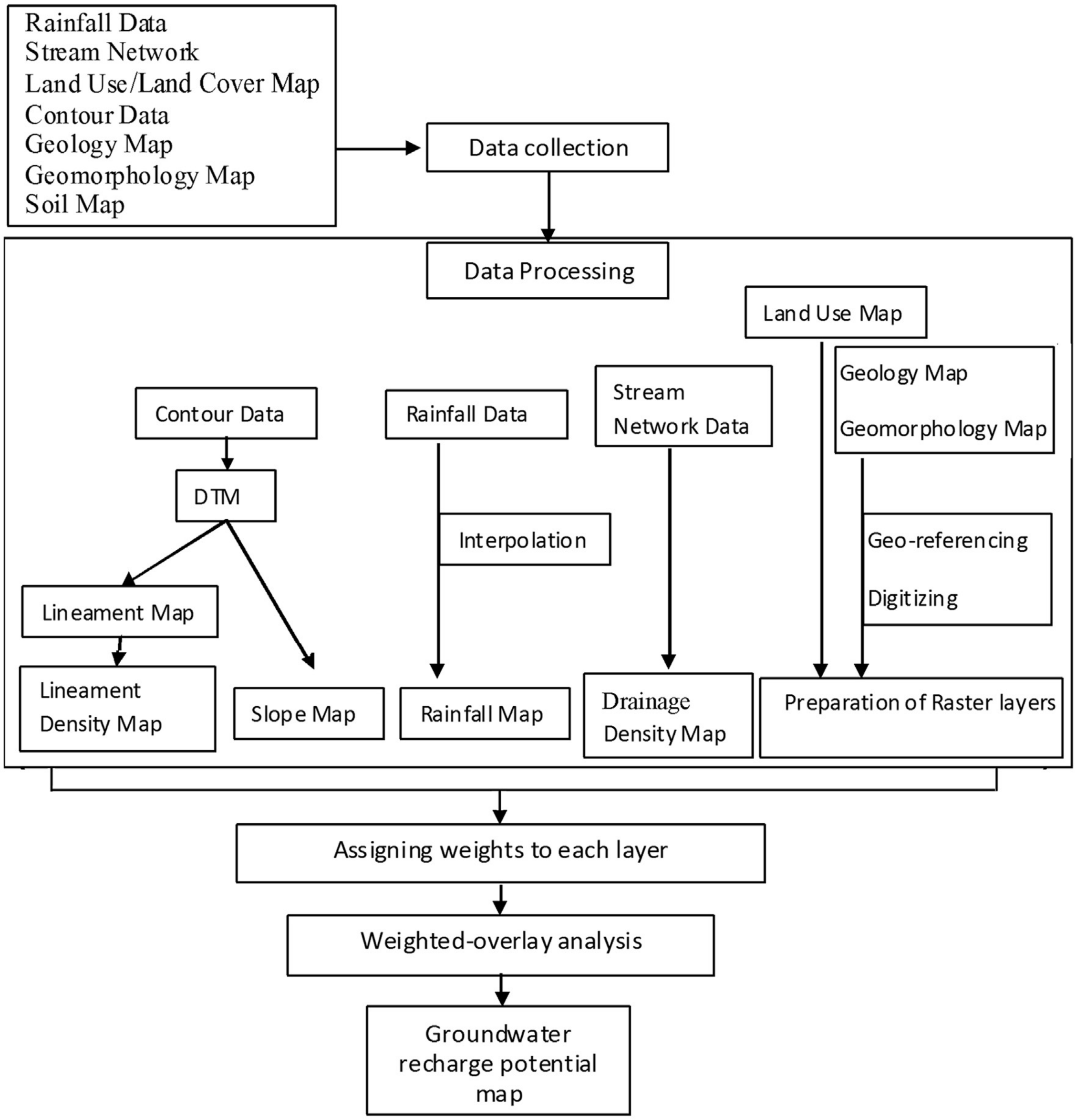

Figure 2. Flow chart of the methodology employed in the study to delineate groundwater recharge potential of Ambalantota, Sri Lanka.

General foliation of the rocks in the area is in north-west south-east direction. Zones with less compaction, and with a higher degree of weathering and fracturing facilitate infiltration of the runoff, and hence are more suitable for groundwater recharging (Krishnamurthy et al., 2000). Therefore, weights for each rock type were assigned by considering the permeability of rock types based on their textural properties and potential of weathered/fractured zone formation.

The soil cover map (Land Use Division – Department of Irrigation Sri Lanka, 1988) and geomorphological map of Sri Lanka (Verstappen and Hoschtitzky, 1987) were obtained from the European Soil Portal (European Soil Portal, 2014) and subsequently geo-rectified and digitized (Figs. 9 and 10 respectively). The most prominent soil types in Ambalantota area are reddish brown earths and solodized solonetz. Reddish brown earths generally possess a clayey texture, while the solodized solonetz shows a leached sandy to loamy horizon on a very hard impervious argillic (Bt) horizon consisting of clay or sandy clay (Moormann and Rojanasoonthon, 1968). The southern region of Ambalantota area mainly consists of reddish brown earths with a high amount of gravel in sub soil and low humic gley soils. Reddish brown earths and low humic gley soils facilitate suitable soil conditions for cultivations (Moormann and Rojanasoonthon, 1968). In addition, Ambalantota encompasses bands of alluvial soils of variable drainage and texture extending from north-west to south-east direction. Further, the coastal belt of Ambalantota is characterized by regosols on recent beach and sand dunes. A few rock knob plains can also be seen in the north-east and south-west regions of the study area. Permeability of each soil type has been considered when assigning weights to each soil class in this study, since permeability is directly related to infiltration and percolation rates.

The land use/land cover, lithology, geomorphology and soil layers were converted into raster format from vector format.

Finally, the weighted linear combination method was adopted to develop the groundwater recharge potential index of each pixel in the area utilizing the following equation:

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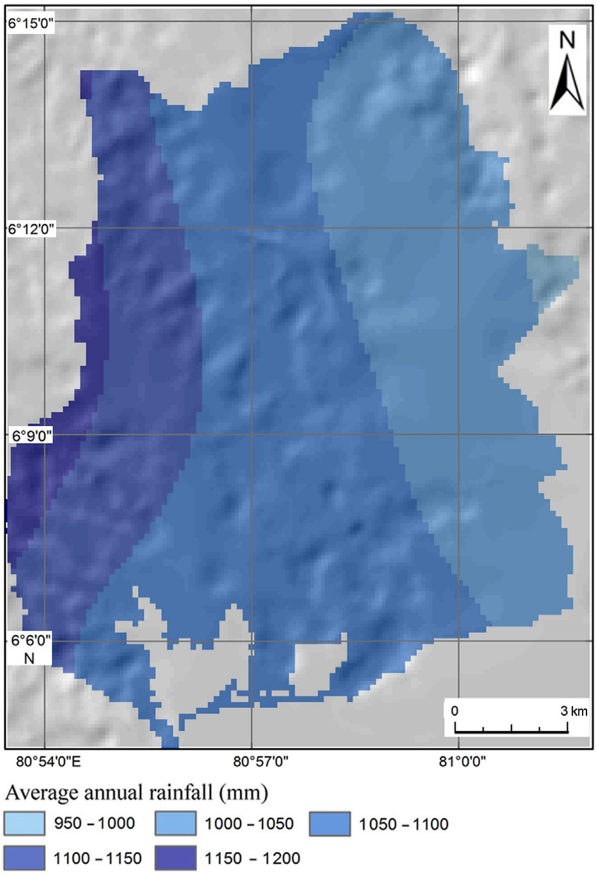

Figure 3. Average annual rainfall map of Ambalantota, Sri Lanka.

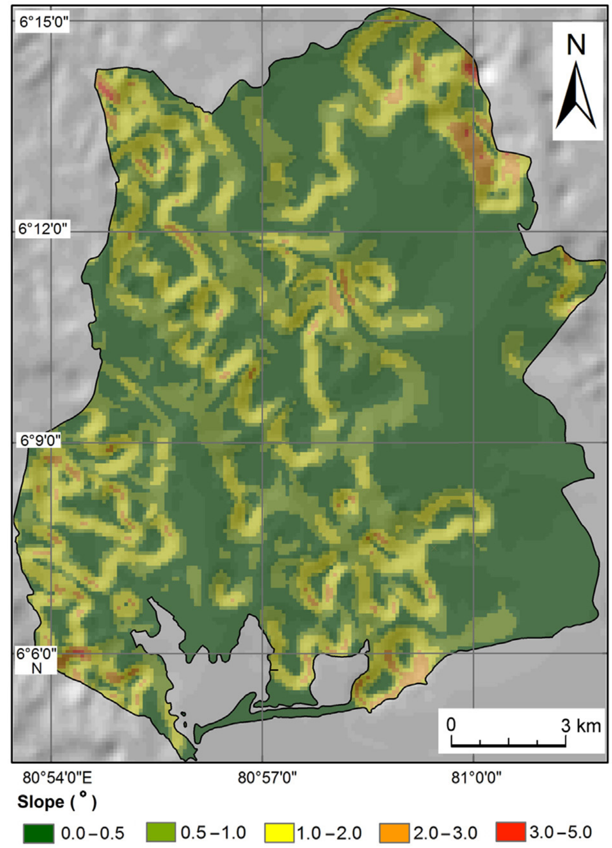

Figure 5. Slope map of Ambalantota, Sri Lanka.

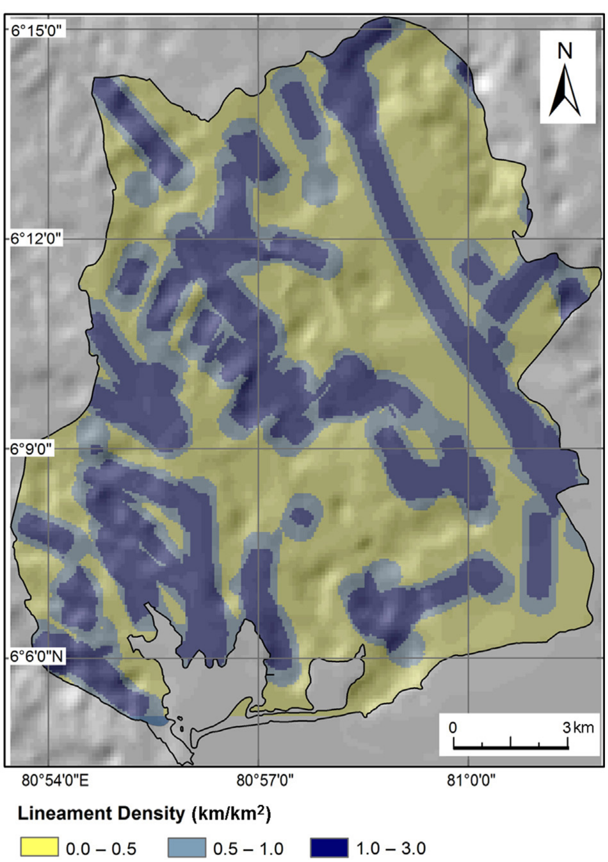

Figure 4. Lineament density map of Ambalantota, Sri Lanka.

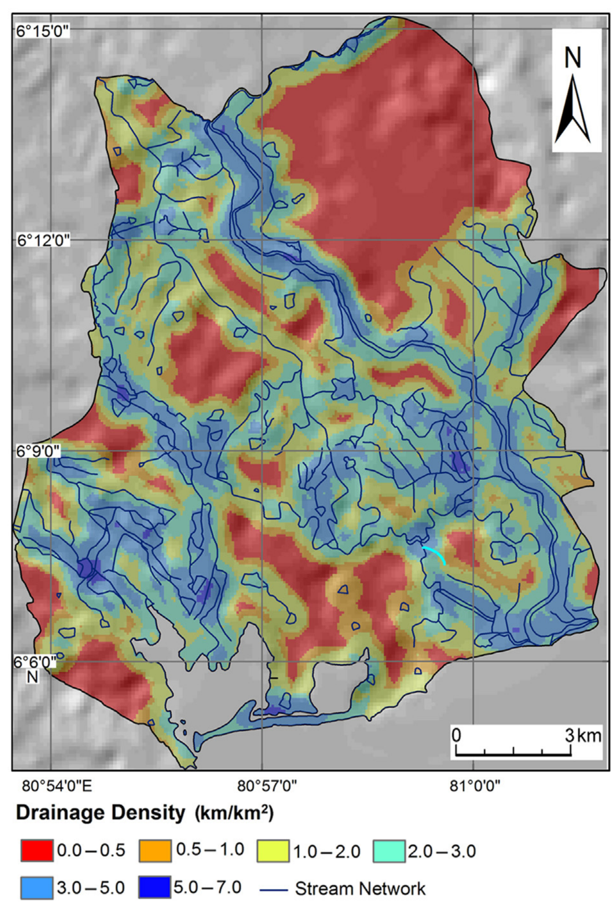

Figure 6. Drainage density map of Ambalantota.

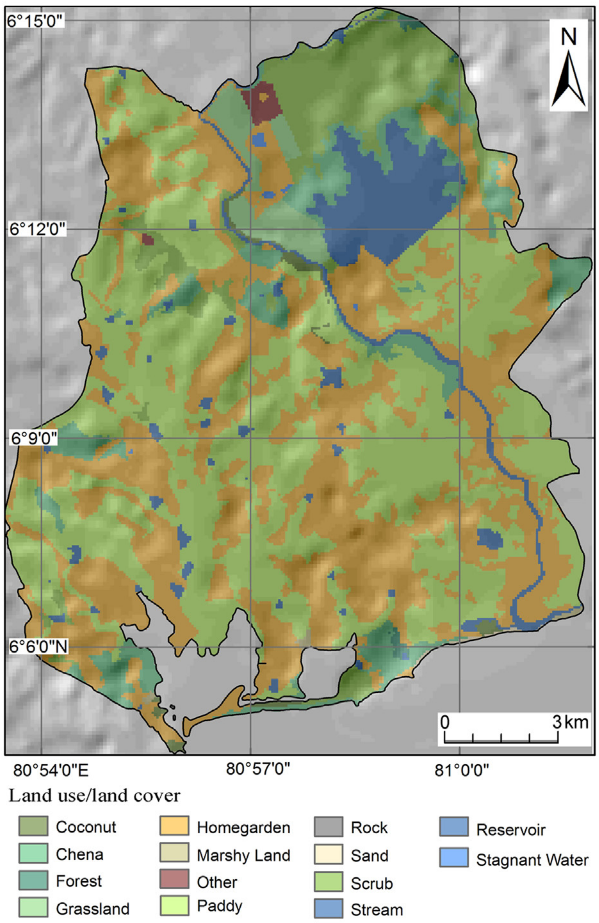

Figure 7. Land use/Land cover map of Ambalantota, Sri Lanka.

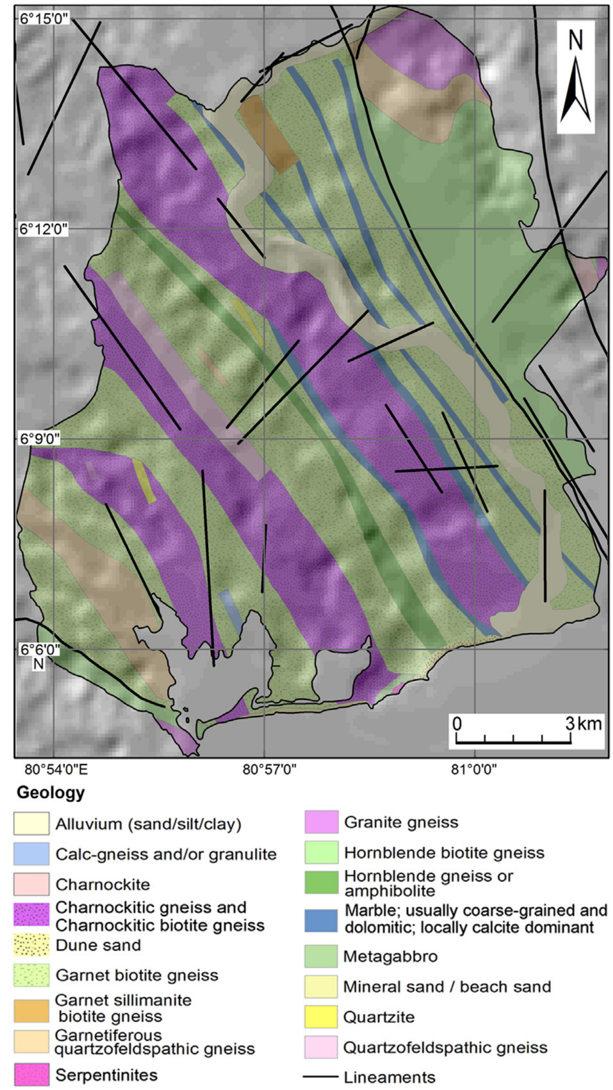

Figure 8. Lithological map of Ambalantota, Sri Lanka.

$$Pr = RF_w RF_r + LG_w LG_r + GG_w GG_r + SG_w SG_r + LD_w LD_r + DD_w DD_r + LC_w LC_r + SC_w SC_r$$

where, Pr is the groundwater recharge potential index, RF is the rainfall index, LG is the lithology index, GG is the geomorphology index, SG is the slope gradient index, LD is the lineament density index, DD is the drainage density index, LC is the land cover/land use index and SC is the soil cover index. The subscripts 'w' and 'r' refer to the weight of a theme and the rank of individual features of a theme respectively. Ranks assigned to each parameter influencing groundwater potential are given in Table 1.

Groundwater recharge potential zones in Ambalanthota area were demarcated by assigning weights to different classes in each theme on the basis of their relative contributions towards recharging (Table 2). Field work was carried out in order to inspect the accuracy of raw data. Further, the artificial recharge potential zone map was field verified to examine whether the identified zones are in accordance with the field conditions. In addition, land use/land cover layers were superimposed over a Landsat-8 natural colour composite in order to assess their accuracy and up-to-dateness. This comparison showed that there is no notable difference between raw data and existing land use/land cover of the study area.

4. Results and discussion

The resultant groundwater recharge potential map was categorized into three classes as low, moderate and high, illustrating the capacity for artificial recharge in the study area as shown in Fig. 11.

The resultant map layer depicts a great deal of artificial recharging capacity for groundwater in the study area. Around 5% of the land of Ambalantota falls into the high artificial recharge potential zone, while 44% of the area belongs to the moderate artificial recharging potential zone according to the statistical results. The Ambalantota area possesses considerable artificial recharge potential mainly due to the availability of irrigation channels, reservoirs, paddy cultivation and flat terrain conditions. The area where the Walawe River flows also indicates a high to moderate recharging potential, possibly due to the availability of significant amounts of surface water and high infiltration rates triggered by soils and lineaments. Furthermore, the fluctuation of water level in the wells in accordance with the water level of rivers and irrigation channels is an indication of the natural recharging procedure throughout the year.

Artificial recharging structures can be implemented in Ambalantota area in order to improve the replenishment of the groundwater resources. Percolation pits, recharge basins, recharge wells, ridges and furrows, check dams, gully control/stone wall structures, contour bunding, trenching and land

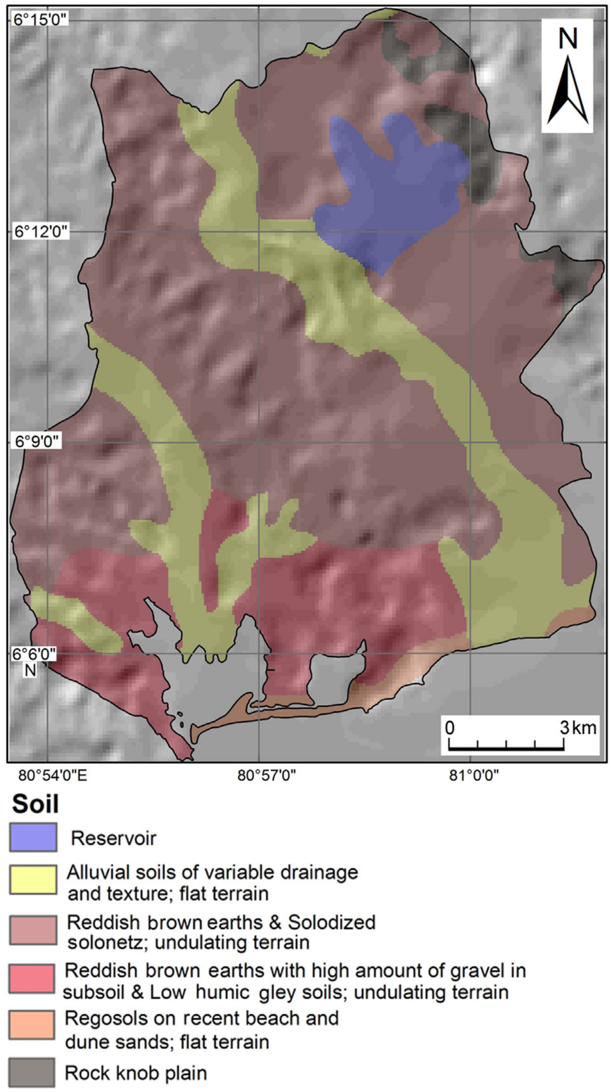

Figure 9. Soil map of Ambalantota, Sri Lanka.

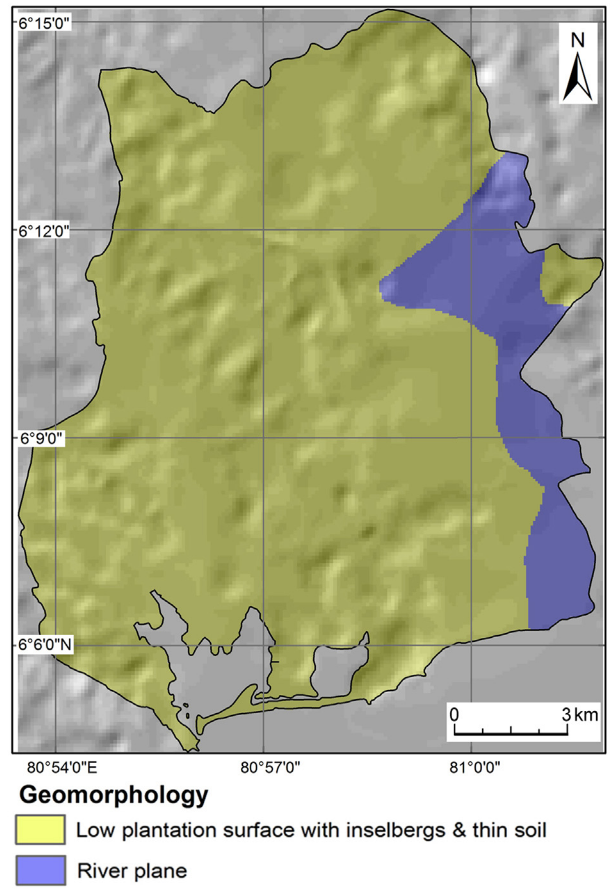

Figure 10. Geomorphological map of Ambalantota, Sri Lanka.

flooding are some of the artificial recharging methods which can be employed in such endeavour (Central Ground Water Board-India, 2007).

Moreover, the results of the study can be improved by increasing the accuracy and spatial resolution of the data. The methodology employed in this study can be generalised for the entire Hambantota District by using appropriate parameters, ranks and weights. Further, it can be extended into other areas of the dry zone of the country to identify potential groundwater recharging zones with suitable modifications. The field verifications are useful in identifying the most suitable artificial recharge structures to replenish groundwater in the study area based on existing terrain conditions, land use/land cover and drainage system. Hence, it will provide clear guidelines to the decision makers in implementing proper groundwater management endeavours.

Numerous studies have been carried out in arid areas of the world to identify groundwater potential zones and artificial recharge potential zones by using geospatial technologies. Kumar et al. (2007) and Manap et al. (2013) employed a knowledge-driven factor analysis for delineating groundwater potential zones. Similar methodologies were used by Krishnamurthy et al. (2000) and Jothiprakash et al. (2003) in delineating artificial recharge potential zones. This is a subjective approach, where the accuracy of final results depends significantly on thematic layers and corresponding weightage factors used in the study. Multi Influencing Factor (MIF) technique has been used in assigning weights in the studies carried out by Magesh et al. (2012) and Manikandan et al. (2014) to identify groundwater potential zones. In addition, Krishnamurthy et al. (2000), Kumar et al. (2007) and Prasad et al. (2008) investigated the delineation of groundwater potential zones in hard rock terrains with varying geological conditions by utilizing geo-spatial technologies.

Integrating influential factor layers using weighted overlay method on a GIS platform has been often employed in delineating artificial recharge potential zones by various researchers such as Shaban et al. (2006), Yeh et al. (2009) and Subagunasekar and

Table 1
Ranks assigned to the parameters influencing groundwater recharge potential (modified after Shahid et al., 2000; Jaiswal et al., 2003; Basavaraj and Nijagunappa, 2011; Magesh et al., 2012; Sarup et al., 2011; Yeh et al., 2014; S. Weerawarnakula personal communication, March 21, 2014).

Parameter	Rank assigned
RF_r	15
LG_r	15
GG_r	12
SG_r	11
LD_r	13
LC_r	10
DD_r	10
SC_r	14

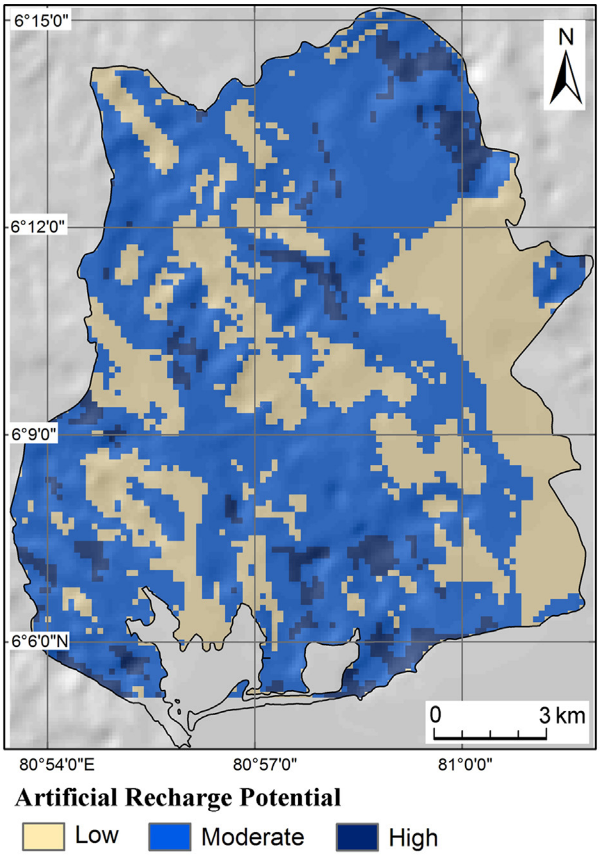

Figure 11. Groundwater recharge potential zone map of Ambalantota, Sri Lanka.

Sashikkumar (2012). Krishnamurthy et al. (2000) used a weighted aggregation method to integrate different thematic layers in order to demarcate groundwater recharge potential zones in hard rock terrain. This approach was based on logical conditioning and reasoning and can be adapted elsewhere with suitable modifications. Saraf and Choudhury (1998) and Shashikkumar and Metilda (2012) also used a similar approach to identify artificial recharge sites in hard rock terrain. Ghayoumian et al. (2005) used a decision support system (DSS) to analyse the integrated thematic layers in a GIS environment. Riad et al. (2011b) investigated both the weighted overlay method and the boolean logic method in delineating artificial recharging sites. Results of this study explain that the weighted overlay model can provide more accurate results. However, boolean true-false map is suggested as a first estimator since it is easier and less time consuming. Riad et al. (2011a) revealed that fuzzy logic can provide classification for each zone identical to the weighted overlay method. Hence, fuzzy logic can be used for more specific and accurate assessment of selected locations in each zone identified through the weighted overlay method. Results of research carried out by Magesh et al. (2012) in Tamil Nadu, India to delineate groundwater potential zones using remote sensing, GIS and multi influencing factor (MIF) techniques identify soil type and slope as the most influential factors in groundwater augmentation in the study area. A similar study carried out in Maharashtra, India found that river terraces and water bodies with alluvium have excellent groundwater recharge potential, while areas with buried pediplain and black cotton soil tend to have a good groundwater recharge potential (Sarup et al., 2011). The same study reveals a good interrelationship among geological units, hydro-morphological units and lineament density. Yeh et al. (2014) employed GIS based factor analysis followed by stable base-flow

Table 2
Weights assigned to classes of each theme based on their influence to groundwater recharge (modified after Shahid et al., 2000; Jaiswal et al., 2003; Kumar et al., 2007; Basavaraj and Nijagunappa, 2011; Magesh et al., 2012; Sarup et al., 2011; Yeh et al., 2014; S. Weerawarnakula personal communication, March 21, 2014).

Themes and classes	Weight assigned
Geomorphology	
River plane	7
Low plantation surface with inselbergs and thin soil	3
Land use/Land cover	
Plantation	
• Coconut	6
• Other	4
Chena	5
Forest	3
Grass land	3
Home garden	2
Marshy land	7
Paddy	7
Rock	2
Sand	8
Scrub	5
Water bodies	
• Streams	8
• Reservoirs	8
• Abandoned reservoirs	6
• Stagnant water	8
Soil	
Alluvial soils of variable drainage and texture, flat terrain	4
Reddish brown earths and solodized solonetz, undulating terrain	4
Reddish brown earths with high amount of gravel in sub soil and low humic gley soils, undulating terrain	6
Regosols on recent beach and dune sands, flat terrain	8
Rock knob plain	1
Geology	
Alluvium (sand/silt/clay)	6
Calc-gneiss and/or granulite	2
Massive rock with less fractures	2
• Charnockite	
• Metagabbro	
Charnockitic gneiss and charnockitic biotite gneiss	2
Dune sand	8
Gneissic rock	3
• Garnet biotite gneiss	
• Garnetiferous quartzofeldspathic gneiss	
• Granite gneiss	
Highly weathered rocks	4
• Garnet sillimanite biotite gneiss	
• Hornblende biotite gneiss	
• Hornblende gneiss (amphibolite)	
Marble, usually coarse-grained and dolomitic, locally calcite dominant	5
Mineral sand/beach sand	7
Quartzite and quartz rich	5
Serpentinites	2
Slope (°)	
0–0.5	9
0.5–1	8
1–2	6
2–3	4
3–5	3
5–10	1
Drainage density (km/km^2)	
0–0.5	1
0.5–1.0	2
1.0–2.0	3
2.0–3.0	5
3.0–5.0	6
5.0–7.0	8
Rainfall (mm)	
950–1000	2
1000–1050	3
1050–1100	4
1100–1150	6
1150–1200	9

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Table 2 (*continued*)

Themes and classes	Weight assigned
Lineament density (km/km^2)	
0–0.5	1
0.5–1	4
1–3	6

(SBF) techniques to assess the characteristics of groundwater recharge in Wu River Basin, Taiwan. The SBF technique was used to separate base-flow from total stream flow discharge to estimate groundwater recharge in a mountainous basin scale.

Researchers have emphasized the ability of remote sensing and GIS techniques in groundwater studies as well as its cost and time effectiveness in such studies. The number of different thematic layers, their accuracy and assigned weights in a weighted overlay analysis can have a significant effect on the accuracy of the results in groundwater studies. However, it is noteworthy that a disparity in weights given for certain themes and classes based on varied considerations by researchers can be generally observed in different studies. Thus, availability of thematic data, their accuracy level, local conditions and considerations play an important role in such groundwater management endeavours.

5. Conclusions

Delineation of groundwater recharge potential zones in Ambalantota area, Hambantota District was conducted utilizing GIS techniques that provided an effective methodology in the context of time, labour and cost. Parameters such as rainfall, lineament density, slope, drainage Density, land use/land cover, lithology, geomorphology and soil cover map layers were integrated on a GIS platform employing the weighted linear combination method. Results of this study reveal a significant amount of artificial recharging capacity in Ambalantota. Around 49% of Ambalantota area was found to have a high to moderate capability in artificial recharging. The resultant suitability map and the methodology employed in this study will serve as a guideline for future water management projects. The methodology used here can be applied in other areas of the world experiencing water stress conditions with appropriate modifications. Such endeavours can be used to analyse the potential for artificial recharge in arid zones to ensure sustainable groundwater utilization.

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References

Basavaraj, H., Nijagunappa, R., 2011. Identification of groundwater potential zone using geoinformatics in Ghataprabha basin, North Karnataka, India. International Journal of Geomatics and Geosciences 2, 91–109.

Bouwer, H., 2002. Artificial recharge of groundwater: hydro-geology and engineering. Hydrogeology Journal 10 (1), 121–142.

Bhattacharya, A.K., 2010. Artificial ground water recharge with a special reference to India. International Journal of Research and Reviews in Applied Sciences 4 (2), 214–221.

Central Ground Water Board-India, 2007. Manual on Artificial Recharge of Groundwater. Ministry of Water Resource Board, Government of India.

Eid, M.M., Abdel Rahman, M.T., Zaghloul, E.A., Elbeih, S.F., 2006. Integrated remote sensing and GIS for proposing groundwater recharge locations: case study at West El-Nubariya Canal, Egypt. The Egyptian Journal of Remote Sensing and Space Science 9, 113–134.

Elbeih, S.F., 2007. Impact of Groundwater Recharge on the Surrounding Environment. Ph.D. thesis. Faculty of Engineering, Ain Shams University, Egypt.

European Soil Portal, 2014. The Soil Maps of Asia. Retrieved May 05, 2014 from: http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/asia/lists/clk.htm.

Geological Survey and Mines Bureau of Sri Lanka, 2001. Sri Lanka 1:100,000 Geology (Provisional Map Series), Rakwana-Tangalla Map. Geological Survey and Mines Bureau of Sri Lanka.

Ghayoumian, J., Ghermezcheshme, B., Feiznia, S., Noroozi, A.A., 2005. Integrating GIS and DSS for identification of suitable areas for artificial recharge, case study Meimeh Basin, Isfahan, Iran. Environmental Geology 47 (4), 493–500.

Ghayoumian, J., Saravi, M.M., Feiznia, S., Nouri, B., Malekian, A., 2007. Application of GIS techniques to determine areas most suitable for artificial groundwater recharge in a coastal aquifer in southern Iran. Journal of Asian Earth Sciences 30, 364–374.

Hambantota District Secretariat, 2011. Hambantota District Secretariat-Overview. Retrieved June 18, 2014 from: http://www.hambantota.dist.gov.lk/index.php?option=com_content&view=article&id=4&Itemid=63&lang=en.

Jaiswal, K., Mukherjee, S., Krishnamurthy, J., Saxena, R., 2003. Role of remote sensing and GIS techniques for generation of groundwater prospect zones towards rural development–an approach. International Journal of Remote Sensing 24 (5), 993–1008.

Jothiprakash, V., Marimuthu, G., Muralidharan, R., Senthilkumar, N., 2003. Delineation of potential zones for artificial recharge using GIS. Journal of the Indian Society of Remote Sensing 31 (1), 37–47.

Krishnamurthy, J., Mani, A., Jayaraman, V., Manivel, M., 2000. Groundwater resources development in hard rock terrain–An approach using remote sensing and GIS techniques. International Journal of Applied Earth Observation and Geoinformation 2 (3–4), 204–215.

Kumar, P.K.D., Gopinath, G., Seralathan, P., 2007. Application of remote sensing and GIS for the demarcation of groundwater potential zones of a river basin in Kerala, southwest coast of India. International Journal of Remote Sensing 28, 5583–5601.

Land Use Division – Department of Irrigation Sri Lanka, 1988. Soil Map of Sri Lanka. Land Use Division Irrigation Department, Sri Lanka and ITC, Netherlands.

Magesh, N.S., Chandrasekar, N., Soundranayagam, J.P., 2012. Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geoscience Frontiers 3 (2), 189–196.

Manap, M.A., Sulaiman, W.N.A., Ramli, M.F., Pradhan, B., Surip, N., 2013. A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia. Arabian Journal of Geosciences 6 (5), 1621–1637.

Manikandan, J., Kiruthika, A.M., Sureshbabu, S., 2014. Evaluation of groundwater potential zones in Krishnagiri District, Tamil Nadu using MIF Technique. International Journal of Innovative Research in Science, Engineering and Technology 3 (3), 10524–10534.

Moormann, F.R., Rojanasoonthon, 1968. No 72: Soils of Thailand, a Reconnaissance Survey with Map Showing the General Soil Conditions, Soil Survey Reports of the Land Development Department, Ministry of National development, Soil Survey Division, Bangkok, Thailand.

Nagarajan, M., Singh, S., 2009. Assessment of groundwater potential zones using GIS technique. Journal of the Indian Society of Remote Sensing 37, 69–77.

Prasad, R.K., Mondal, N.C., Banerjee, P., Nandakumar, M.V., Singh, V.S., 2008. Deciphering potential groundwater zone in hard rock through the application of GIS. Environmental Geology 55 (3), 467–475.

Punmia, B.C., Jain, Ashok K., Jain, Arun K., 2005. Soil Mechanics and Foundations. Laxmi Publications (P) Ltd, New Delhi, India.

Riad, P.H., Billib, M.H., Hassan, A.A., Omar, M.A., 2011a. Water scarcity management in a semi-arid area in Egypt: overlay weighted model and Fuzzy logic to determine the best locations for artificial recharge of groundwater. Nile Basin Water Science & Engineering Journal 4 (1), 24–35.

Riad, P.H., Billib, M., Hassan, A.A., Salam, M.A., El Din, M.N., 2011b. Application of the overlay weighted model and Boolean logic to determine the best locations for artificial recharge of groundwater. Journal of Urban and Environmental Engineering 5 (2), 57–66.

Saraf, A.K., Choudhury, P.R., 1998. Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. International Journal of Remote Sensing 19 (10), 1825–1841.

Sarup, J., Tiwari, M.K., Khatediya, V., 2011. Delineate groundwater prospect zones and identification of artificial recharge sites using geospatial technique. International Journal of Advance Technology & Engineering Research 1, 6–20.

Saunders, R.J., 2001. Artificial Recharge of Groundwater as a Water Management Option for Eastern Maine. M.Sc. thesis. Bio-Resource Engineering, University of Maine, USA.

Sener, E., Davraz, A., Ozcelik, M., 2005. An integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. Hydrogeology Journal 13 (5–6), 826–834.

Senanayake, I.P., Dissanayake, D.M.D.O.K., Puswewala, U.G.A., 2012. Analysis of the abundance of abandoned tanks in Hambantota District, Sri Lanka using GIS techniques. The Egyptian Journal of Remote Sensing and Space Science 15 (2), 143–150.

Senanayake, I.P., Welivitiya, W.D.D.P., Nadeeka, P.M., Puswewala, U.G.A., Dissanayake, D.M.D.O.K., 2013. Remote sensing and GIS based assessment of water scarcity: a case study from Hambantota district, Sri Lanka. In: Proceeding of 34th Asian Conference on Remote Sensing, Bali, Indonesia, pp. 2478–2485.

Shaban, A., Khawlie, M., Abdallah, C., 2006. Use of remote sensing and GIS to determine recharge potential zones: the case of Occidental Lebanon. Hydrogeology Journal 14 (4), 433–443.

Shahid, S., Nath, S.K., Roy, J., 2000. Groundwater potential modelling in a soft rock area using GIS. International Journal of Remote Sensing 21, 1919–1924.

Shashikkumar, M.C., Metilda, L.D., 2012. GIS approach for the demarcation of groundwater recharge potential zones in hard rock terrain. International Journal of Earth Sciences and Engineering 5 (1), 117–120.

Shiklomanov, I., 1993. World fresh water resources. In: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's Fresh Water Resources. Oxford University Press, New York.

Solomon, S., Quiel, F., 2006. Groundwater study using remote sensing and geographic information systems (GIS) in the central highlands of Eritrea. Hydrogeology Journal 14 (6), 1029–1041.

Sophocleous, M., 2002. Interactions between groundwater and surface water: the state of the science. Hydrogeology Journal 10 (1), 52–67.

Subagunasekar, M., Sashikkumar, M.C., 2012. GIS for the assessment of the groundwater recharge potential zone in Karunkulam block, Thoothukudi district, Tamil Nadu, India. International Journal of Current Science 159–162.

Tweed, S.O., Leblanc, M., Webb, J.A., Lubczynski, M.W., 2007. Remote sensing and GIS for mapping groundwater recharge and discharge areas in salinity prone catchments, southeastern Australia. Hydrogeology Journal 15 (1), 75–96.

Verstappen, H.T., Hoschtitzky, M.E.D., 1987. Geomorphological Map of Sri-Lanka. Department of Cartography, ITC, Netherlands.

Weerasekara, W.L., Mayadunna, B.B., Senanayake, I.P., Dissanayake, D.M.D.O.K., 2014. Integrated remote sensing and GIS in lineament mapping for groundwater exploration–A case study in Ambalantota, Sri Lanka. In: Proceeding of SAITM Research Symposium on Engineering Advancements 2014. South Asian Institute of Technology and Medicine, Malabe, Sri Lanka, pp. 62–65.

Wada, Y., van Beek, L.P., van Kempen, C.M., Reckman, J.W., Vasak, S., Bierkens, M.F., 2010. Global depletion of groundwater resources. Geophysical Research Letters 37 (20), L20402.

Yeh, H.F., Lee, C.H., Hsu, K.C., Chang, P.H., 2009. GIS for the assessment of the groundwater recharge potential zone. Environmental Geology 58 (1), 185–195.

Yeh, H.F., Lin, H.I., Lee, S.T., Chang, M.H., Hsu, K.C., Lee, C.H., 2014. GIS and SBF for estimating groundwater recharge of a mountainous basin in the Wu River watershed, Taiwan. Journal of Earth System Science 123 (3), 503–516.

Zubair, L., 2002. El Nino-southern oscillation influences on rice production in Sri Lanka. International Journal of Climatology 22, 249–260.

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