Integrated Remote Sensing and GIS Approach for Demarcation of Groundwater Potential Zones in Ambalantota Divisional Secretariat

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Abstract: Demand for water in Hambantota district is increasing rapidly due to agricultural activities, massive on-going development projects, industrialization and consequent population growth. Implementation of a proper water management system is essential in facing predicted water stress conditions where groundwater resources can play an important role. Delineation of groundwater potential zones, recharge zones and groundwater quality assessment can be identified as the three main segments of groundwater management. Geospatial technologies can be successfully utilized in such endeavours due to the cost and time effectiveness.

Ambalantota Divisional Secretariat was selected as the study area in this research work. Rainfall, contour, geology, geomorphology, soil and drainage network data along with Landsat 7 ETM+ image were utilized to develop relevant thematic layers in delineating groundwater potential zones and recharging sites through a weighted overlay model on a GIS platform.

Field studies were carried out to collect samples for water quality analysis and to verify the results. Groundwater quality map of the area was generated based on the results of laboratory analysis, depicting suitability level for drinking.

The results indicate that Ambalantota DS has significant groundwater potential and recharge potential, hence can be effectively utilized as a hub for a water management system in Hambantota district.

Keywords: Groundwater recharge, lineament mapping, weighted overlay analysis, water scarcity

1. Introduction

The available surface water resources scarcely fulfil the current water requirement in the world (U.S. Department of the Interior, 2013). Therefore, groundwater exploration has become a vital practice in present day.

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Although Sri Lanka receives a considerable amount of average annual rainfall varying from 900 mm to 5,500 mm (Department of Agriculture, Sri Lanka, 2006), it is not distributed evenly over the island. Consequently, the three main climatic zones namely, dry, intermediate and wet zone were defined based on the distribution of rainfall (Rainforest Rescue International, 2005). Sri Lanka has a considerable volume of groundwater stocks that can be utilized in drinking and domestic purposes (Machanayake and Bandara, 1999). Therefore, groundwater can be identified as an invaluable resource, which can contribute in fulfilling the demand for fresh water in the dry zone of Sri Lanka.

Hambatota can be identified as a district affected by severe periodic droughts due to its surface water scarcity caused by less rainfall, high evoporation rates and soil conditions (Senanayake*et al.*, 2012). Agriculture is the main livelihood in the district and is based on proper water supply.

Furthermore, rapid on-going development projects in the area such as, international harbour and airport, conference hall, infrastructure developments, etc. increase the demand for fresh water dramatically (Urban Development Authority, 2011). According to the Comprehensive Assessment of the Freshwater Resources of the World (1997), it can be predicted that two thirds of the world population will face water stress conditions by 2025(Senanayake *et al.*, 2012). Further, UN studies explain that countries with water withdrawal rate of 40% or more will face severe water stress conditions. The withdrawal rate of available water resources in South Asia is 48%. Hence, Sri Lanka should be properly prepared to face this predicted water stress conditions (Senanayake *et al.*, 2012).

Thus, establishing a proper water management system is a necessity, where groundwater management plays an integral role. Remote sensing and Geographic Information System (GIS) techniques can be successfully utilized for demarcation of groundwater potential zones and groundwater recharge zones due to time and cost effectiveness.

Ambalantota Divisional Secretariat (DS) of Hambantota district was selected for this study. The area covers approximately 203 sq. km and bounded by latitudes $80^0$53' - 81^0 02'E and longitudes 6^0 04' - 6^0 15'N. Walawe River and Ridiyagama Tank provide water-rich conditions in the area. Consequently, Ambalantota can be effectively used as a hub in a water management system designed to face the predicted water stress conditions in Hambantota district.

This study was carried out to identify the groundwater potential zones, delineate the suitable sites for artificial recharge and to assess the groundwater quality in Ambalantota DS by employing remote sensing and GIS technologies.

2. Methodology

2.1 Delineation of groundwater potential zones and recharge zones in Ambalantota DS.

Factors such as rainfall, lineament density, slope, drainage density, land use, lithology, geomorphology and soil types were employed in this study to delineate groundwater potential zones and recharge zones.

Average annual rainfall was calculated using the monthly rainfall data of the study area from 1992 to 2012 obtained from the Meteorological Department of Sri Lanka. Afterwards, the average annual rainfall data were interpolated using the "Kriging" technique to develop the rainfall map of Ambalantota DS.

Lineament mapping was carried out using automatic extraction method with the aid of Digital Terrain Model (DTM) of Ambalantota developed by using 5 m interval contour data prepared by the Survey Department of Sri Lanka. Eight shaded relief images were generated using the DTM corresponding to eight contrast illumination directions viz. 0^0, 45°, 90°, 135°, 180°, 225°, 270° and 315° and subsequently compressed into 2 distinct images. The two resultant images were subjected to automatic lineament extraction. The resultant lineament layer was masked to remove man made linear features such as roads, dams, etc. and the lineament density map was prepared.

Slope map was generated using the Triangular Irregular Network (TIN) of Ambalantota interpolated using the contour data.

Stream density map of the area was developed utilizing the stream network data prepared by the Survey Department of Sri Lanka.

Supervised classification of the Landsat ETM+ image was conducted to prepare the land use layer of the study area.

Lithological map prepared by the Geological Survey and Mines Bureau was scanned, geo-rectified and digitized.

The geomorphological and the soil map of the area were obtained through http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/asia/lists/clk.htm. Subsequently, the maps were geo-rectified and digitized.

Finally, the weighted overlay analysis method was employed to generate the maps depicting groundwater potential and suitable recharging sites by assigning appropriate ranks to different themes (Table 2.1) and weights to classes in each theme (modified from Shahid *et al*, 2000; Gunawardena and Dissanayake, 2007; Dissanayake, 2013; S. Weerawarnakula, personal communication, March 21, 2014)) on the basis of their relative contributions towards both potential and recharging separately (Table 2.2).

Table 2.1: Ranks assigned for the thematic layers.

Criteria	Ranks Assigned	
	G/W Potential	G/W Recharging
Rainfall	25	20
Lithology	20	15
Geomorphology	15	15
Slope	10	15
Lineaments	10	10
Landuse	10	10
Drainage Density	5	10
Soil	5	5

Table 2.2: Weights assigned for classes of each theme.

Criteria	Weights Assigned	
	G/W Potential	G/W Recharging
Geomorphology		
River plane	7	7
Low plantation Surface with Inselbergs and thin soil	3	3
Land use		
Chena	5	6
Home Garden	2	2
Paddy	6	7
Scrub	2	6
Water bodies	8	8
Soil		
Alluvial soils of variable drainage and texture; flat terrain	6	6
Reddish brown earths and solodized solonetz; undulating terrain	6	6
Reddish brown earths with high amount of gravel in sub soil &low humic gley soils; undulation terrain	6	6
Regosols on recent beach and dune sands; flat terrain	2	6
Rock knob plain	2	2
Geology		
Alluvium (Sand/Silt/Clay)	7	7
Calc-gneiss and/ or granulite	2	2
Massive rock with less fractures	1	2
Chanockitic gneiss and chanockitic biotite gneiss	2	2
Dune sand	2	6
Gneissic rock	2	3
Highly weathered rocks	3	4
Marble usually coarse and dolomitic locally calcite dominant	4	5
Mineral sand/ beach sand	2	5
Quartzite and quartz rich	2	5
Serpentines	2	2
Slope (Degrees)		
0-0.5	9	9
0.5-1	8	8
1-2	6	6
2-3	4	4
3-5	3	3
5-10	1	1
Drainage Density (m/m^2)		
0-0.5	8	1
0.5-1	6	2
1-2	5	3
2-3	3	5
3-5	2	6
5-7	1	8
Rainfall (mm)		
950-1000	2	2
1000-1050	3	3
1050-1100	4	4
1100-1150	6	6
1150-1200	9	9

Lineament Density (m/m²)		
0 - 0.0005	1	1
0.0005 - 0.001	4	4
.001 -.003	6	6

2.2 Preparing groundwater quality maps of Ambalantota DS

Five major water quality parameters, pH, turbidity, dissolve oxygen (DO), total dissolve solids (TDS) and electrical conductivity were considered in this study to assess the groundwater quality in Ambalantota. Water samples of the study area were collected in a grid pattern and, subsequently analyzed in the laboratory. Thematic layers of the measured groundwater parameters were generated using Inverse Distance Weighted (IDW) interpolation technique by combining with the data obtained from the Water Resource and Drainage Board. The final groundwater quality map was prepared to depict the combined result of the analysis of water quality parameters using a weighted overlay analysis by assigning equal weights.

3. Results and Discussion

Developed groundwater potential and recharge zone maps were classified into three classes as low, moderate and high,assigning appropriate break values (Figure 3.1). Further, the groundwater quality map was classified as low, moderate and high based on the level of suitability for drinking (Figure 3.2).

The results illustrate approximately 89% of the DS falls under high to moderate groundwater potential zones and nearly94% of the area under high to moderate groundwater recharge zones.

Hardness, turbidity and electrical conductivity of the groundwater in the coastal region of the DS have higher values due to saline water intrusion resulting low suitability for drinking in the Southern region of the study area. The quality of groundwater improves from Southern region towards North.

Groundwater table can be artificially recharged by pebble bed method, percolation pits, recharge wells, ridges and furrows check dams, gully control/stone wall structures, contour bunding, trenching and land flooding.

Further studies employing time series data, geophysical surveys, etc. are suggested to verify the results and to improve the accuracy of the model.

The methodology adopted in this study can be generalized to whole Hambantota. Further, it can be employed for the whole dry zone in Sri Lanka using appropriate regional parameters.

4. Conclusion

This study was carried out to demarcate groundwater potential zones, suitable sites for artificial groundwater recharge and to assess the groundwater quality of Ambalantota DS.

The results of the study explain that Ambalantota DS has a considerable groundwater potential and a high groundwater recharging capacity; hence can be utilized as a hub in a future water management system designed for the Hambantota district. Groundwater in the Northern part of Ambalantota is suitable for drinking, while groundwater in Southern part can be utilized with purification.

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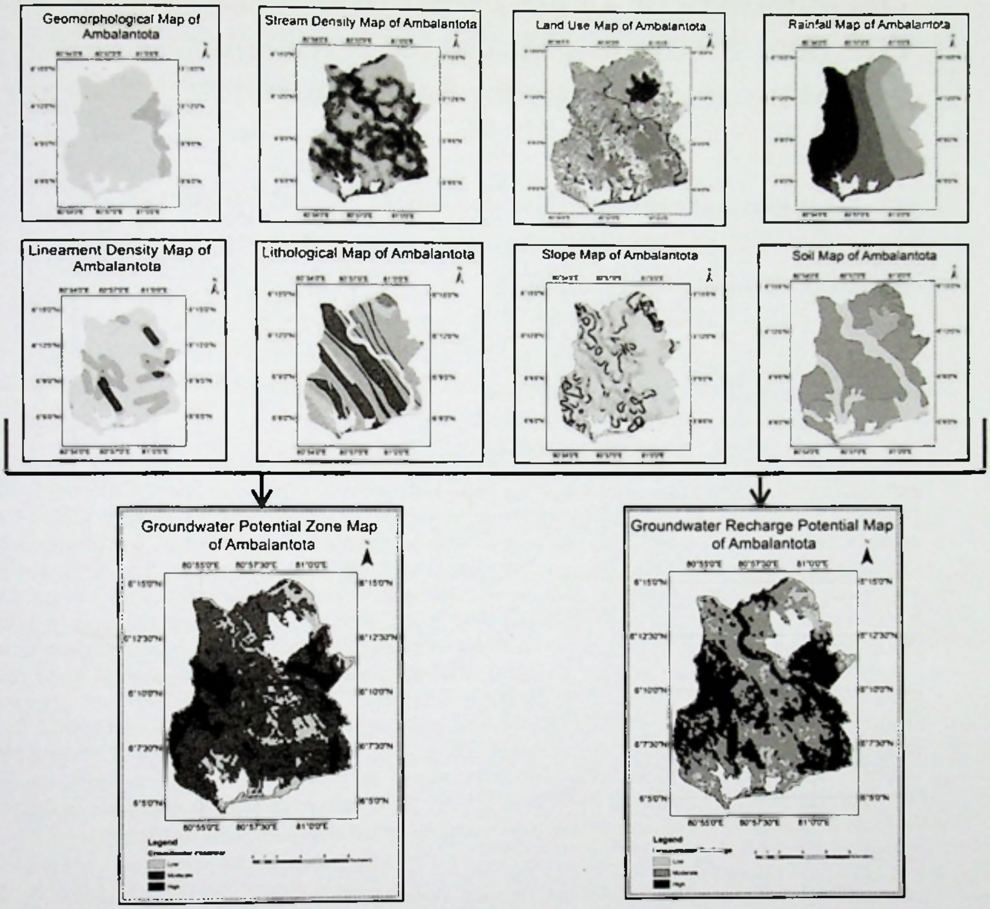

Figure 3.1: Groundwater potential and recharge zone maps of Ambalantota

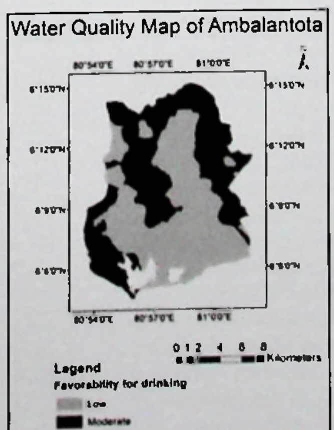

Figure 3.2: Groundwater quality map of Ambalantota DS.