DEMARCATION OF GROUNDWATER POTENTIAL REGION USING GIS TECHNIQUES: A Case Study in Nintavur DSD

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Abstract

An efficient planning of groundwater expansion using modern techniques is essential for the proper consumption and management of this precious but reduction natural resource. With the advent of powerful, professional techniques for water management have advance, of which GIS and RS (Geographical Information Systems and Remote Sensing) are of great significance. Groundwater resources potential has been evaluated in Nintavur DSD using GIS and RS techniques. With the help of Survey of Sri Lanka toposheets and satellite data, various thematic maps like base map, drainage map, geology map, geomorphology map, slope map, drainage density map, population density map and land use map of the study area have been prepared using Arc GIS software. These thematic maps have been integrated and appropriate weights have been assigned to various factors controlling rate of groundwater. The results show that there are four categories of groundwater potential zones ranging from very good to poor. The categorization of groundwater potential zones is in general agreement with the acquired yield data of the existing dug wells. This depicts the favourable potential zones in the study area for evaluation of groundwater resources. Finally it is concluded that the GIS and RS techniques are very efficient and useful for the demarcation of groundwater potential zones.

Key words: *Groundwater, GIS, Groundwater Potential Zones, Thematic Maps, Overlay Analysis.*

1.1 Introduction

Water is the most valuable and essential resource for sustenance of life and also for any developmental activity. With the surface water sources dwindling to meet the various demands, groundwater has become the only reliable resource. Excessive groundwater withdrawal has caused a severe lowering of the water table in some well fields of central and northern Jordan (Margane, 1995). Deterioration of groundwater quality became an increasing serious problem in recent years. The concept of groundwater vulnerability is based on the assumption that the physical environment may provide some degree of protection to groundwater against natural impacts, especially with regard to contaminants entering subsurface environment (Napolitano, 1995). Consequently, some land areas are more vulnerable to groundwater contamination than others. Over the past 20 years, groundwater vulnerability maps have been developed in many countries as a basis for developing land use strategies that take into consideration aspects of protection of groundwater from pollution. The ultimate goal of vulnerability maps is the subdivision of the area into several hydrogeological units with different levels of vulnerability. These maps show the distribution of highly vulnerable areas, in which pollution is very common because contaminants can reach the groundwater within a very short time. However, such maps do not replace more detailed studies of the geological and hydrogeological conditions of particular sites for the envisaged use.

The indiscriminate use of this vital natural resource is creating groundwater mining problem in various parts of world (Todd, 2007). Hence, the groundwater resource should be evaluated thoroughly, carefully and reliably on a real-time basis to meet the ever growing needs. Remote Sensing (RS), with its advantage of spatial, spectral and temporal availability of data covering large and inaccessible area within short time, has become a very rapid and cost effective tool in assessing, monitoring and conserving groundwater resources. Geographical Information System (GIS) is a powerful environment for real time database development, especially in studies such as delineating groundwater potential zones and recharge sites, groundwater modeling studies etc.

Many researchers have carried out groundwater modeling through the application of GIS. In the present study IRS P6 (Resourcesat-1) - LISS III and IRS 1D- PAN merged RS data acquired geo-referenced at the scale of 1:50,000 and Survey of Sri Lanka toposheet No.57 and 58 have been used for preparation of various thematic maps such as base, drainage, drainage density, geology, geomorphology, slope, soil and land use/land cover. The pre-monsoon well yield data have been acquired from the monitoring of four hundred and thirty eight existing wells in the study area. An attempt has been made to integrate these data through the application of GIS to delineate the groundwater potential zones in the study area.

Figure 01: Study Area

1.2 Study Area

Nintavur DSD is located at east of Sri Lanka. It lies between 81^0 50’ 42” - 81^0 50’ 44”E longitude and 7^0 28’ 04” - 7^0 19’ 36”N latitude and forms part of 57 and 58 toposheets. The location map is shown in Figure 01.Theareal extent of Nintavur DSD is 38.3 sq. km. It is mainly drained by Kaliodi and Vettaru rivers. Physiography of the area exhibits flat region with covering larger part of the study area.

1.3 Objective of the Study

The general objective is to delineate groundwater potential areas, in Nintavur DSD. Systematic groundwater studies utilizing Remote Sensing, field studies, Digital Elevation Models (DEM) and Geographic Information Systems (GIS).

The specific objectives are;

- To delineate the groundwater potential zones using relevant data (rainfall, topography, geology, soil, etc.)
- To develop a GIS model that can identify groundwater potential zones based on the thematic maps
- To validate the results of this study with data from the field

1.4 Materials and Methods

The study area is characterized by deep soil cover, paddy cultivation, monsoon rainfall and lack of soil moisture for dry season (April to August) of the year. Seasonal droughts coupled with increase in groundwater exploitation results in decline in groundwater levels. In order to manage and develop sustainable scheme, it is vital to delineate the groundwater potential zones. Various physiographic details are shown in the base map in Figure 01.

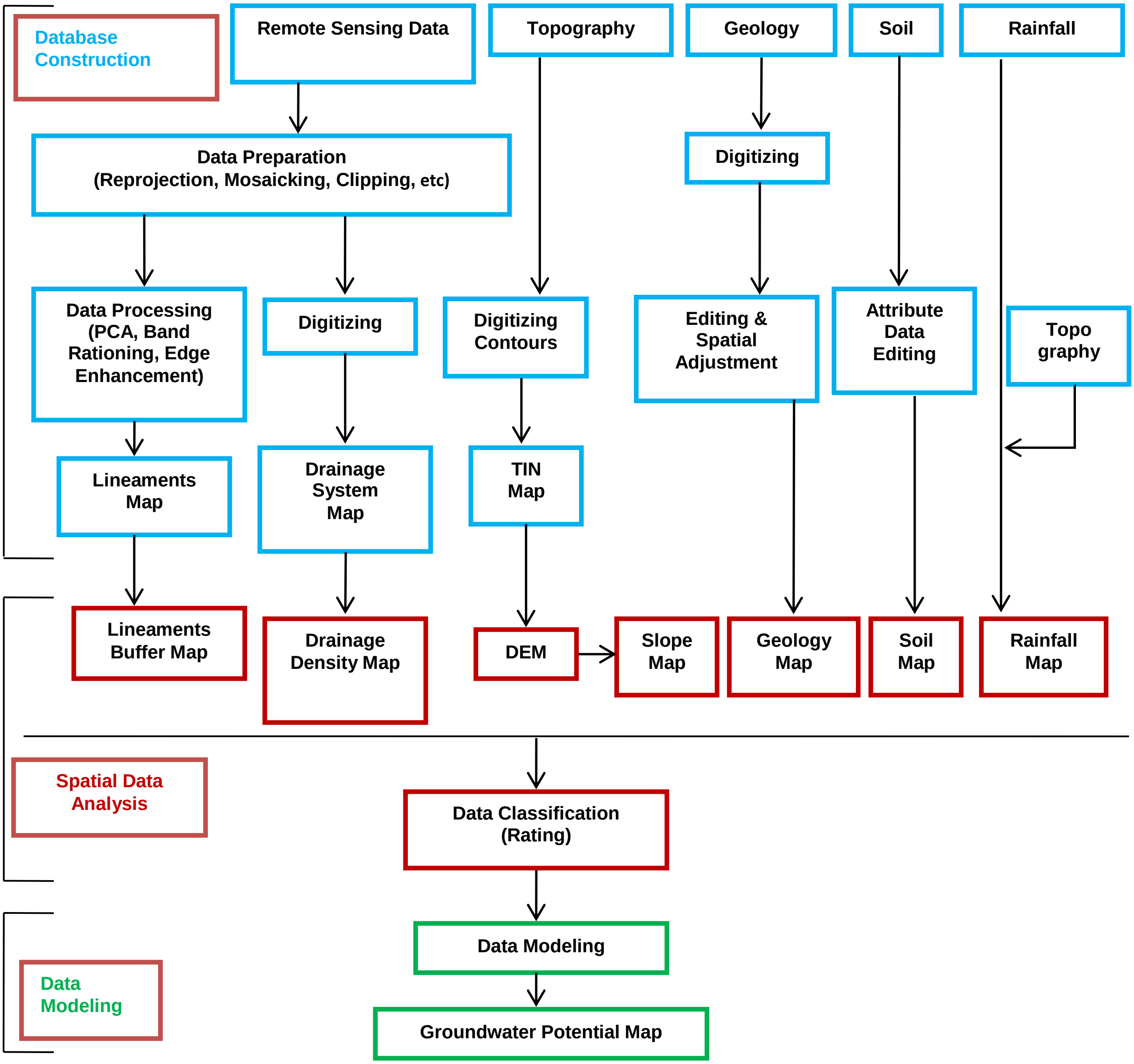

Figure 02: Flow Chart Illustrates Methodology of Groundwater Potential Zones Map

In the present study, IRS P6 (Resourcesat-1) - LISS III and IRS 1DPAN merged remote sensing data, geo-referenced at the scale of 1:50,000 and Survey of Sri Lanka toposheet nos. 57 and 58 have been used for preparation of various thematic maps like base map, geology map, drainage map, geomorphology map, slope map, soil map, drainage density map and land use/ land cover map of the study area. The thematic maps prepared were integrated using the Arc GIS software for generation of groundwater potential zones map. Flow chart depicting the broad methodology adopted in the study for preparing the groundwater potential zones map is shown in the Figure 02. The significance of each theme in evaluation of groundwater potential zones is briefly presented as follows:

1.4.1 Geology

The geological background of Ampara district can be discerned by means of lithology and morphological features which involves a study of the Precambrian rocks of the oldest geological period and those of the modern quaternary period. Of the collections of rocks found in the Nintavur DSD formed by the metamorphosis of the sedimentary layers in geological basins in Pre-Cambrian times, the most widely distributed are those of the Vijayan complex. Of these, granite gneiss, argon gneiss, biotite gneiss, hornblende biotite gneiss and migmatic feldspar, graphite calcgranulite or gneiss and crystalline are the significant.

The eastern side of the reservoir consists of granite gneisses with, pinkish micro line. Even, sand deposits and distributes at along the coastal belt. South-west region is occupied by granite gneiss. In the southern part, biotite gneiss, hornblende migmatic and granitic deposit occur. In the eastern part, beach and dune sands brown, grey sand deposit occurs. I part and within the beach and dune sands brown, grey sand deposits calcium concentrate as patches (Figure 03), these deposits will not allow water to percolate. As a result, these areas have less groundwater potential.

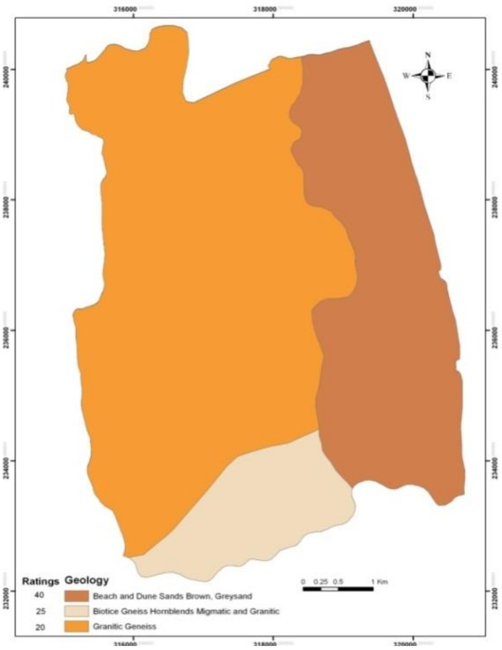

Figure 03: Geology

1.4.2 Drainage

Drainage pattern of any terrain reflects the characteristics of surface as well as subsurface formations. The drainage pattern, in general is dendritic. Drainage density (expressed in terms of km/sq.km) indicates closeness of spacing of channels. More the drainage density, higher would be runoff. Thus, the drainage density characterizes the runoff in the area or in other words, the quantum of rainwater that could have infiltrated. Hence lesser the drainage density, higher is the probability of recharge or potential groundwater zone. Most of the drainage originates from the western part of the area. The drainage density in the area has been calculated after digitization of the entire drainage pattern. It varies from 0.5 km/sq. km to more than 2 km/sq. km. The drainage map is shown in Figure 04 and the drainage density map is shown in Figure 04.

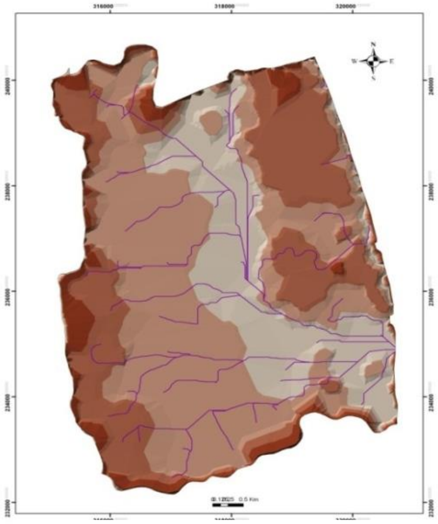

Figure 04: Drainage Density

1.4.3 Slope

Slope of any terrain is one of the factors controlling the infiltration of groundwater into subsurface, hence it is also an indicator for the suitability for groundwater prospects. In the gentle slope area, the surface runoff is slow allowing more time for rainwater to percolate, whereas, steep slope area facilitates high runoff allowing less residence time for rainwater and hence comparatively less infiltration. Slope map of the area as shown in Figure 05, indicates that it varies from 0^0 to more than 10^0. The slopes have been classified into five categories, that is, 0-0.5^0, 0.5^0-2^0, 2^0-5^0, 5^0-10^{0}and more than 10^0. Most of the central of the study area is found to have a slope of 0-0.5^0 and is favourable from groundwater potential point of view.

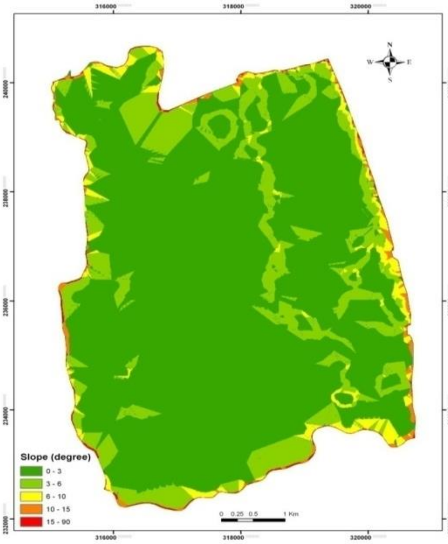

Figure 05: Slope

1.4.4 Geomorphology

Geomorphology reflects various landforms and structural features. Many of these features are favourable for the occurrence of groundwater and are classified in terms of groundwater potentiality. These units are shown in Figure 06. The major geomorphological units found in the study area are Beach and Dune Sands Brown, Grey sand, Biotice Geneiss Homblends Magnetic and Granitic and Granitic Geneiss Soil.

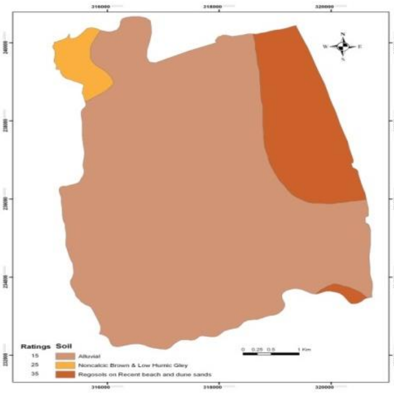

Figure 06: Geomorphology

1.4.5 Soil

Land is one of the important natural resources and is a precious asset. The actions related to land and water management influences the vegetation and land use/land cover. Information on existing land use /land cover and pattern of their spatial distribution forms the basis for any developmental planning. Current land use has to be assessed for its suitability for groundwater prospects. Land use/land cover map is shown as Figure 07.

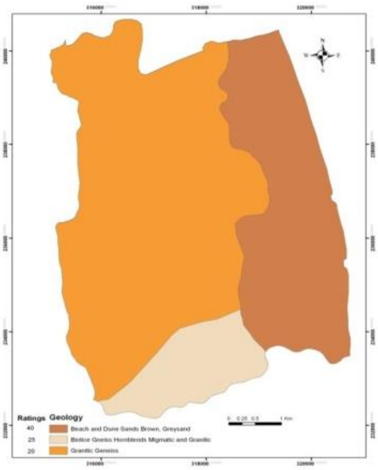

Figure 07: Soil Type

1.4.6 Lineament Density

The mapping of lineaments is important in groundwater resources studies because many groundwater potential zones are located along fracture zones. Lineaments, which are linear or curvilinear features, can play a major role in identifying suitable sites for groundwater abstraction because they reflects rock structures, fractures and faults through which water can store and travel up to several kilometers. On the basis of the above air photo and satellite imagery interpretation and filtering techniques, 03 series of regional lineaments have been identified within the study area (Figure 08).

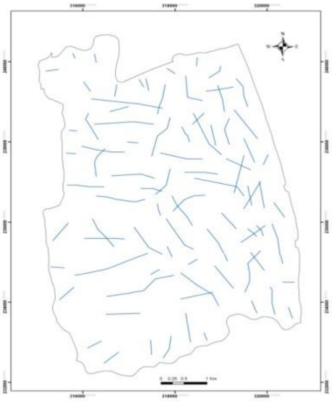

Figure 08: Lineament Density

1.4.7 Population Density

The impacts of population on the quantitative water needs of a locality are related to population density (that is, how the population is distributed geographically), and to the rate of increase or decrease in population growth. Because population changes affect the availability and quality of the water sources that can be drawn upon for use.

Population density is measured as the number of persons per unit area of land. The population increasing rate is 3.5 per cent and density stands at 461 persons per square kilometre in the district (2008). Population density a significant increase ground water mining.

1.5 Integration of Thematic Maps through GIS

Integration of various thematic maps describing favourable ground water zones, into a single groundwater potential zones map has been carried out through the application of GIS. Arc GIS software has been utilized for analysis purpose. It required mainly three steps:

1. Spatial Database Building
2. Spatial Data Analysis
3. Data Integration

1.5.1 Spatial Database Building

The tools provided in Arc GIS Catalogue of Arc GIS software have been used to create the scheme for feature data sets, tables, geometric networks and other items inside the database.

Secant method of geo-database building has been followed. The following steps were involved to create coverage and INFO tables for each thematic map:

1. Digitization of scanned maps.
2. Editing for errors, dangle, etc.
3. Topology building
4. Attributes assignments
5. Projection
6. Buffering

The study area boundary, village, rivers, streams and ponds have been digitized. Toposheets of 1:50,000 scales have been used to prepare base map, drainage map, geomorphology map; slope map; land use/land cover map, geological map and soil map have also been digitized. After digitization, these maps have been processed for editing of errors, dangles, pseudo-nodes, etc. Attributes to these maps have been added. Any coverage attributes needs to be added to available features to differentiate them. Buffering of 100 m for lineaments and dykes have been done and a separate thematic map has been created.

Table 01: Weights Assign

Parameter	Class	Rating	Weight
Elevation (m)	3 – 6	50	0.0455
	6 – 9	40	
	9 – 12	20	
	> 12	10	
Soil	Regosols on recent beach and dune sands; flat terrain	35	0.2518
	Alluvial soils of variable drainage and texture; flat terrain	25	
	Noncalcic Brown soils & Low Humic Gley soils; undulating terrain	15	
Geology	Biotice Gneiss Hornblends Migmatic and Granitic	20	0.3487
	Granitic Geneiss	25	
	Beach and Dune Sands Brown, Grey sand	40	
Drainage density (Km/Km2)	0 – 0.5	50	0.0905
	0.5 – 1	20	
	1.5 – 2	10	
Slope (degrees)	>10	10	0.0258
	5 - 10	20	
	2 – 5	30	
	0.5 – 2	35	
	0 – 0.5	40	
Lineament Buffer)	0 - 25	50	0.1513
	25 – 50	40	
	50 – 75	25	
	75 - 100	10	

1.5.2 Spatial Data Analysis

It is an analytical technique associated with the study of locations of geographic phenomena together with their spatial dimension and their associated attributes (like table analysis, classification, polygon classification and weight classification). The various thematic maps as described above have been converted into raster form considering 100 m as cell size to achieve considerable accuracy. These were then reclassified and assigned suitable weight. The weights assigned to various features in the themes are shown in Table 01.

1.5.3 Data Integration

Each thematic map such as geology, geomorphology, drainage density, lineament, land use/land cover and slope provides certain clue for the occurrence of groundwater. In order to get all these information unified, it is essential to integrate these data with appropriate factor. Although, it is possible to superimpose this information manually, it is time consuming and error may occur. Therefore, this information is integrated through the application of Arc GIS software.

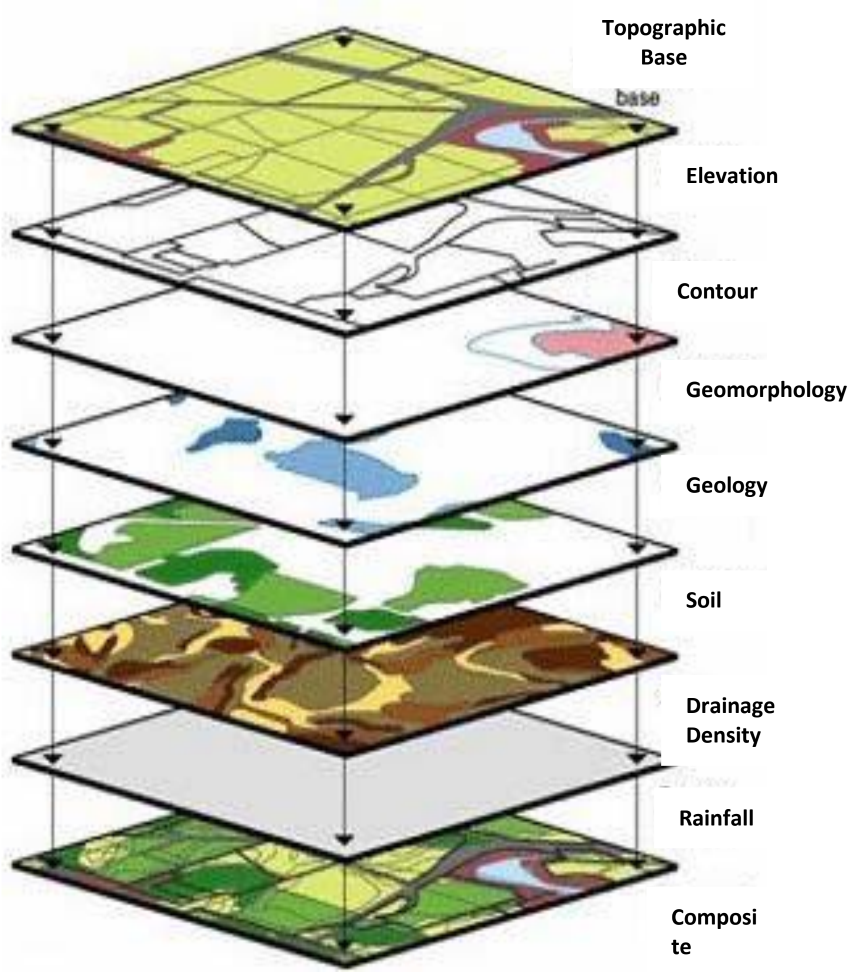

Figure 08: Overlay Analysis

1.6 Generation of Groundwater Potential Zones Map

In the present study, each theme considered is assigned a weight depending on its influence on storage and transmission of groundwater. These weights represent the relative importance of a theme vis-a-vis the objective. The different units in each theme are assigned knowledge-based hierarchy of weight from 1 – 4 on the basis of their significance with reference to their groundwater potential. In this weight, 1 denotes poor groundwater potential, 2 moderate, 3 high and 4 very high groundwater potential. Various thematic maps are reclassified on the basis of weight assigned and brought into the "Raster Layer" (Figure 08) using weighted overlay method model of builder in Arc GIS software. The weight for different layers have been assigned considering similar work carried by many researchers such as Krishnamurthy *et al*., (1996), Jothiprakash *et al*., (2003), Rokade *et al*., (2007), and Chowdhury *et al*., (2009). A "Simple Arithmetical Model" in Arc GIS software has been adopted to integrate various thematic maps by averaging the weight, classifying potential zones based on decision rules and groundwater potential zones map has been generated.

1.7 RESULTS

Nintavur DSD basin has been classified into four groundwater potential zones namely: 'Very high', 'High', 'Moderate', 'Low' covering 0.9, 39.6, 56.9, and 2.5% of the study area, respectively as shown in Table 02. The maximum area, particularly the southern part is characterized by good potential occupying about 39% of total area, whereas, very good potential area is marked by only 0.9% as shown in Figure 10. The integrated map thus, developed could be useful for various purposes such as sustainable development of groundwater in the Nintavur DSD.

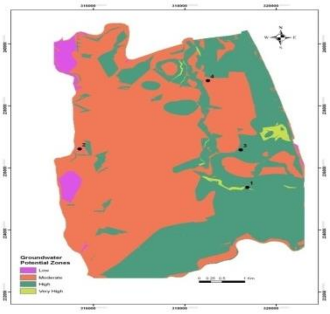

Figure 09: Application of Model Builder

Table 02: Groundwater Potenti

GMP Potential Class	Low	Moderate	High	Very High
Area %	2.5	56.9	39.6	0.9

1.8 Conclusions

A study was carried out to delineate groundwater potential zones in Nintavur GND using Remote Sensing and GIS techniques. In the present study, IRS P6 (Resourcesat-1) – LISS III and IRS-1D PAN merged remote sensing data, geocoded at the scale of 1:50,000 and Survey of Sri Lanka toposheets have been used for preparation of various thematic maps such as base, drainage, geology, soil, geomorphology, slope, drainage-density and land use/land cover. The different units in each theme are assigned knowledge-based hierarchy of weightage from 1 - 4 on the basis of their significance with reference to their groundwater potential.

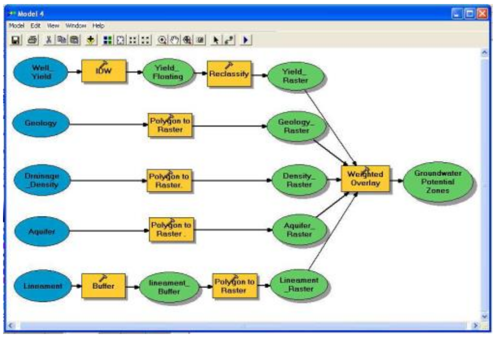

Figure 10: Groundwater Potential Zone

The layers were then integrated in the GIS environment using Arc GIS software to delineate various groundwater potential zones in the study area. The study area was categorized into five groundwater potential zones namely 'very high', 'high', 'moderate', and 'low' covering different percentages of the study area. Since the major portion (more than 40%) of the study area exhibits 'very high' to 'high' groundwater prospect, it can be inferred that the groundwater resource is adequately available in the study area. The categorizations of groundwater potential zones were in general agreement with the available yield data of existing dug wells. Further, comparison of groundwater yield data collected from the field also supports that there are more number of high yield wells in the favourable zones derived from GIS. This depicts the favourable prospective zones in the study area for evaluation of groundwater potential. Further, the results of this study demonstrated that the Integrated Remote Sensing and GIS based approach is a powerful tool for assessing groundwater potential based on which suitable locations for groundwater withdrawals could be identified.

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