SITE SUITABILITY ANALYSIS FOR WATER HARVESTING STRUCTURES IN SURIYAWEWA, HAMBANTOTA DISTRICT USING GIS TECHNIQUES

Indishe Prabath Senanayake

(07/8015)

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Degree of Master of Philosophy

Department of Earth Resources Engineering

University of Moratuwa

Sri Lanka

February 2012

SITE SUITABILITY ANALYSIS FOR WATER HARVESTING STRUCTURES IN SURIYAWEWA, HAMBANTOTA DISTRICT USING GIS TECHNIQUES

Indishe Prabath Senanayake

(07/8015)

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Thesis submitted in partial fulfillment of the requirements for the Degree Master of Philosophy.

Department of Earth Resources Engineering

University of Moratuwa

Sri Lanka

February 2012

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date:

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

The above candidate has carried out research for the MPhil thesis under my supervision.

Signature of Supervisor I: Date:

Signature of Supervisor II: Date:

ABSTRACT

Sri Lanka receives an average annual rainfall varying from 900mm to 6000mm. However, the rainfall is not distributed equally over the island. Hence, traditionally, the country is divided into three main climatic zones as wet zone, dry zone and intermediate zone. Two thirds of the island is occupied by the dry zone, which receives less than 1750mm of average annual rainfall. The dry zone periodically has faced water stress conditions from the past, and Hambantota District appears to be a severely affected area, on the basis of surface water availability. With the ongoing development projects, the demand for water in the district will increase in the next few years.

Therefore, implementation of a proper water management system as well as preservation of existing surface and groundwater resources is essential to overcome this problem.

A methodology is developed to find the most suitable locations for water harvesting structures in Hambantota District by using Geographic Information System (GIS) techniques. Suriyawewa Divisional Secretariat area is selected as the research area considering its average climatic conditions and location within Hambantota District. This methodology can be generalized to the whole District in the first instance.

The research area is hydrologically analyzed to discretize the area into catchments and the preferred catchments to harvest the runoff based on surface area, slope and rainfall are found by using GIS techniques. The selected catchments are then analyzed with geological data and drainage characteristics to find the most suitable catchments to construct reservoirs to store rainwater. The analysis yields four such locations, which were subsequently field verified for spatial accuracy. However detailed local investigations are necessary before proceeding to actual construction of the reservoirs.

Groundwater recharging also plays an important role in water management, as groundwater represents 30.1% of the world's fresh water resources. GIS techniques are employed to integrate data on land use, climate, soil, stream pattern and ground slopes, and consequently to find potential areas for groundwater recharging. Here also, detailed local investigation must precede any construction work in the selected areas.

Also, potential areas to implement roof water harvesting projects in Suriyawewa are found by analyzing the rainfall and building cover by using GIS techniques. These areas are recommended to be used as project areas when implementing efficient roof water harvesting methods.

The methodology adopted here for Hambantota District can be used for water management in other Districts of the Dry Zone of Sri Lanka such as Monaragala, Puttalam, Ampara, Badulla and Kurunegala, as a solution for water stress conditions in those areas. An increment in water harvesting can significantly increase the crop yields in these areas and improve the economy as most of the Districts in the Dry Zone are agriculture-based. Also, a proper water management system is a must for the industrial development of the area under focus, while it gives a solution to the problems regarding drinking water. Proper water supply plays a major role in infrastructure development of these areas and would form the foundation for the overall development of the country.

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

ACKNOWLEDGEMENTS

Foremost, I would like to express my sincere gratitude to my supervisors, Prof. U.G.A. Puswewala, Professor at Department of Civil Engineering and Dean of the Faculty of Engineering, University of Moratuwa, and Dr. D.M.D.O.K. Dissanayake, Senior Lecturer at the Department of Earth Resources Engineering, University of Moratuwa and Chairman of the Renewable Energy Authority. Without their immense guidance and persistent help this dissertation would not have been possible.

The research presented in this thesis was carried out at the Department of Earth Resources Engineering, University of Moratuwa under the financial assistance from the University Research Fund. I would like to thank the University of Moratuwa, and the Senate Research Committee for the financial assistance extended.

Beside my supervisors, I would like to thank the chairman of the progress review committee, Prof. S.A.S. Kulatilake, for his encouragement and insightful comments.

I would also like to thank Prof. R.A. Attalage, Director of the Postgraduate Studies Division, University of Moratuwa and his staff for their support.

My sincere thanks also go to Dr. (Mrs.) S.C.S. Karunaratne, Head of the Department of Earth Resources Engineering and Dr. A.M.K.B. Abeysinghe, Research Coordinator at the Department of Earth Resources Engineering, University of Moratuwa, for their kind support.

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations

I owe my deepest gratitude to Mrs. W.L. Gunawardena, Lecturer at the Department of Town and Country Planning, University of Moratuwa for her kind assistance on Remote Sensing and GIS software during this research.

It is with immense gratitude that I acknowledge the support of late Surveyor General Mr. B.J.P. Mendis, Additional Surveyor General Mr. K. Thawalingam and the staff of the Survey Department of Sri Lanka for providing me the digital data of Suriyawewa at a concession.

I am indebted to the staff of Meteorological Department of Sri Lanka, Geological Survey and Mines Bureau and the Irrigation Department of Ambalantota for providing me with the required climatic, geological and irrigation data respectively for this research.

I am grateful to the academic and non-academic staff of the Department of Earth Resources Engineering, and the Department of Civil Engineering, University of Moratuwa for their guidance and support.

Also, I wish to thank library staff and the staff of Examination Division of University of Moratuwa for their help during the work.

My gratitude goes to all the authors and publishers of the literature I used, in this work.

In the field, residents of the study area helped and gave me essential details. I highly acknowledge their support with immense gratitude.

I express my heartfelt gratitude to my parents, family and friends whose moral and emotional support helped me immensely.

Last but not the least, I would like to acknowledge and extend my heartfelt gratitude all of those who supported me in any respect during the completion of this research.

I. P. Senanayake

B.Sc. Eng (Hons)
Department of Civil Engineering
University of Moratuwa, Sri Lanka.
November 01, 2011

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

TABLE OF CONTENTS

Declaration i
Abstract ii
Acknowledgements iii
Table of contents v
List of Figures viii
List of tables xi

1.0 Introduction 1
1.1 Geography and Climate of Sri Lanka 1
1.2 Rainfall and the Climatic Zones of Sri Lanka 1
1.3 Water Supply and Scarcity in Sri Lanka 3
1.4 Water Stress Conditions in Hambantota District 3
1.5 Objectives and the Scope of the Project 4

2.0 Literature Review 5
2.1 Harvesting of Rainwater 5
2.2 Rainwater Harvesting (RWH) Technologies 5
2.3 Factors Affecting Rainwater Harvesting 11
2.4 Project Area: Hambantota District 13

3.0 Methodology 19
3.1 Introduction 19
3.2 Preparation of Digital Maps of Hambantota District 19
3.2.1 Geo-referencing the Scanned Topographical Maps of Hambantota District 19
3.2.2 Digitizing the topographical maps of Hambantota District 20
3.2.3 Generating Digital layers of Hambantota Land Use 20
3.3 Preparation of the Digital Elevation Model (DEM) of Hambantota District Terrain 21
3.3.1 Surface model 22
3.3.2 Digital Elevation Model (DEM) 22
3.3.3 Triangulated Irregular Network (TIN) 22
3.3.4 Raster Surfaces 22
3.3.5 Preparation of the Contour Map of Hamantota District 23
3.3.6 Preparation of the Triangulated Irregular Network (TIN) of Hambantota District 23
3.3.7 Preparation of the Raster DEM/ GRID of Hambantota District 23
3.3.8 Generation of the 3D View of Hambantota Terrain 23
3.3.9 Generation of the Slope Map of Hambantota Terrain 28
3.3.10 Generation of the Aspect of Slope Map 29
3.4 Field Verification of Data 32
3.5 Analysis of Climatic Data 36
3.5.1 Rainfall 36
3.5.2 Temperature 42

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

3.6 Selecting Suriyawewa Divisional Secretariat Area as the Research Area 43
3.7 Location of Suriyawewa Divisional Secretariat Area 43
3.8 Preparation of the Land Use Maps of Suriyawewa 44
3.9 Preparation of the Triangulated Irregular Network of Suriyawewa 51
3.10 Preparation of the Raster DEM/ GRID of Suriyawewa 51
3.11 Generation of the 3D View of Suriyawewa Terrain 51
3.12 Satellite Image of Suriyawewa 51
3.13 ArcHydro 56
3.14 Terrain Preprocessing 56
3.14.1 DEM Reconditioning 56
3.14.2 Fill Sinks 57
3.14.3 Flow Direction 59
3.14.4 Flow Accumulation 59
3.14.5 Stream Definition 62
3.14.6 Stream Segmentation 62
3.14.7 Catchment Grid Delineation 62
3.14.8 Catchment Polygon Processing 65
3.14.9 Drainage Line Processing 68
3.14.10 Drainage Point Processing 68
3.15 Analysing the Slope Map of Suriyawewa 71
3.15.1 Slope Map of Suriyawewa 71
3.15.2 Reclassifying the Slope Map 71
3.15.3 Converting Reclassified Slope Map into a Vector Layer 71
3.15.4 Splitting the Slope Map into Catchments 76
3.15.5 Average Annual Rainfall Map of Suriyawewa 77
3.15.6 Selecting the Catchments to harvest rainwater on the basis of Slope and Surface Area 78
3.15.7 Analysis of the Catchments with the rainfall data 82
3.16 Analysis of the Selected Catchments 90
3.16.1 Catchment ‘cm’ 90
3.16.2 Catchment ‘cf’ 91
3.16.3 Catchment ‘bc’ 91
3.16.4 Catchment ‘ce’ 92
3.16.5 Catchment ‘cy’ 93
3.16.6 Catchment ‘bd’ 93
3.16.7 Catchment ‘ej’ 94
3.16.8 Catchment ‘au’ 95
3.16.9 Catchment ‘bg’ 95
3.16.10 Catchment ‘dm’ 97
3.16.11 Catchment ‘cz’ 98
3.16.12 Catchment ‘el’ 98
3.16.13 Catchment ‘bp’ 99
3.16.14 Catchment ‘bh’ 100
3.16.15 Catchment ‘bj’ 100
3.16.16 Special case at location D 101
3.16.17 Selection of the locations to construct tanks 103

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

3.16.18 Geological Analysis of the locations 104
3.16.19 Field verification of the selected locations 106
3.17 Introducing a methodology to improve the groundwater potential 110
3.17.1 Site suitability analysis for groundwater recharge in Suriyawewa 111
3.18 Site suitability analysis for Rooftop Water Harvesting in Suriyawewa 116

4. Proposals to improve the water management in the project area 118

5. Conclusion 126

6. References 128

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF FIGURES

Figure 1.1	Climatic Zones of Sri Lanka (Source: Department of Agriculture)	2
Figure 2.1	Examples of types of guttering	8
Figure 2.2	Roof top water harvesting storage tank in Hambantota	8
Figure 2.3	Western Australia rainwater harvesting system for animal consumption. The runoff-surface is compacted and treated.	10
Figure 2.4	Various forms of flat-land and inter-row water harvesting; from A – C increasing Catchment to Cropping Ratio (CCR)/ aridity of location.	10
Figure 2.5	Rainwater harvesting categories	11
Figure 2.6	Elements of Rainwater Harvesting System	12
Figure 2.7	Drainage Patterns	13
Figure 2.8	Location of the Hambantota District in Sri Lanka	15
Figure 3.1	Land Use Map of Hambantota District	21
Figure 3.2	Contour Map of Hambantota District	24
Figure 3.3	Triangulated Irregular Network (TIN) of Hambantota District	25
Figure 3.4	Grid/ Raster DEM of Hambantota District	26
Figure 3.5	3D Scene of the Hambantota District Terrain	27
Figure 3.6	Slope Map of Hambantota District (in degrees)	29
Figure 3.7	The eight slope directions	30
Figure 3.8	Aspect of Slope Map - Hambantota District	31
Figure 3.9	Map showing the Field Visit Locations	33
Figure 3.10	Andara Wewa at 'Location 17'	35
Figure 3.11	Paddy Fields at 'Location 21'	35
Figure 3.12	Gonnoruwa Wewa at 'Location 9'	35
Figure 3.13	Distribution of Mean Annual Rainfall of Sri Lanka (in mm)	36
Figure 3.14	Rainfall Stations of Hambantota District	38
Figure 3.15	Average Monthly Rainfall Statistics of Hambantota District	39
Figure 3.16	Average Annual Rainfall Statistics of Hambantota District (1992-2006)	40
Figure 3.17	Average monthly rainfall of Hambantota District	41
Figure 3.18	Average annual rainfall of Hambantota District	41
Figure 3.19	Average Monthly Temperature Statistics of Hambantota District	42
Figure 3.20	Average Annual Temperature Statistics of Hambantota District	42
Figure 3.21	Location of Suriyawewa DS Area in Hambantota District	44
Figure 3.22	Spot Heights Map of Suriyawewa Divisional Secretariat Area	45
Figure 3.23	ArcGIS Model used to generate the Suriyawewa Spot Heights Layer.	46
Figure 3.24	Grama Niladari Divisions of Suriyawewa	47
Figure 3.25	Land Use Map of Suriyawewa	48
Figure 3.26	Tributaries of Suriyawewa	49
Figure 3.27	Contour Map of Suriyawewa	50
Figure 3.28	Triangulated Irregular Network (TIN) of Suriyawewa	52
Figure 3.29	Raster DEM (GRID) of Suriyawewa	53
Figure 3.30	3D Scene of Suriyawewa Terrain	54
Figure 3.31	IIRS Raw Image and Geo-referenced Image	54
Figure 3.32	IIRS Satellite Image of Suriyawewa	55

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Figure 3.33	Change of the Cross Section Profile of a given location after the raw DEM is reconditioned.	56
Figure 3.34	AGREE DEM of Suriyawewa Terrain	57
Figure 3.35	HYDRO DEM of Suriyawewa	58
Figure 3.36	The theory behind Flow Accumulation Grid	59
Figure 3.37	Flow Direction Grid of Suriyawewa	60
Figure 3.38	Flow Accumulation Grid of Suriyawewa	61
Figure 3.39	Stream Grid of Suriyawewa generated by Stream Definition Function overlaid on the Tributaries layer prepared by Survey Department of Sri Lanka.	63
Figure 3.40	Stream Link Grid of Suriyawewa	64
Figure 3.41	Attributes Table of the Catchment Layer	65
Figure 3.42	Catchment Grid of Suriyawewa	66
Figure 3.43	Polygonal Catchment Layer of Suriyawewa	67
Figure 3.44	Drainage Points	68
Figure 3.45	Drainage Point Layer of Suriyawewa	69
Figure 3.46	Methodology followed to prepare the Hydrological Layers of Suriyawewa	70
Figure 3.47	Classification Statistics of Suriyawewa Slope Map	71
Figure 3.48	Slope Map of Suriyawewa	73
Figure 3.49	Reclassified Slope Map of Suriyawewa	74
Figure 3.50	Reclassified Slope Map of Suriyawewa (Converted to vector)	75
Figure 3.51	Adding a Text Field to the Catchment Layer and naming the catchments	76
Figure 3.52	Reclassified slope classes in Catchment ‘ab’	77
Figure 3.53	Average Annual Rainfall Map of Suriyawewa	78
Figure 3.54	The relationship between Head Difference and Slope Angle	79
Figure 3.55	Area calculations of the polygons in catchment ab by using its attribute table	80
Figure 3.56	The thirty selected catchments which drain the highest amount of surface runoff on the basis of surface area and slope	83
Figure 3.57	Reclasssified Rainfall Map of Suriyawewa	84
Figure 3.58	Reclasssified Rainfall Map of Suriyawewa (Converted to polygonal feature class)	85
Figure 3.59	Catchment ‘ce’ with its rainfall classes	86
Figure 3.60	The fifteen catchments selected to harvest runoff water considering rainfall, slope and surface area	88
Figure 3.61	The fifteen catchments which yields the highest amount of runoff with their outlet points	89
Figure 3.62	Catchment ‘cm’	90
Figure 3.63	Catchment ‘cf’	91
Figure 3.64	Catchment ‘bc’	92
Figure 3.65	Catchment ‘ce’	92
Figure 3.66	Catchment ‘cy’	93
Figure 3.67	Catchment ‘bd’	94
Figure 3.68	Catchment ‘ej’	94
Figure 3.69	Catchment ‘au’	95
Figure 3.70	Happoruwa Wewa	96
Figure 3.71	View of downstream paddy fields from Happoruwa Wewa	96
Figure 3.72	Catchment ‘bg’	97

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Figure 3.73	Catchment ‘dm’	97
Figure 3.74	Catchment ‘cz’	98
Figure 3.75	Catchment ‘el’	99
Figure 3.76	Catchment ‘bp’	99
Figure 3.77	Catchment ‘bh’	100
Figure 3.78	Catchment ‘bj’	101
Figure 3.79	Point D (230,540.986 E, 127,975.128 N)	102
Figure 3.80	Selected Locations	103
Figure 3.81	Geology Map of Suriyawewa	105
Figure 3.82	Paddy Fields at Location A	106
Figure 3.83	Paddy Fields at Location B	107
Figure 3.84	Paddy Fields at Location C	107
Figure 3.85	Ranmudu Wewa (left) and Maha Indi Wewa (right)	108
Figure 3.86	Chena cultivations near Point D	108
Figure 3.87	Irrigation Well - Suriyawewa	109
Figure 3.88	Suitable land use classes for groundwater recharging	111
Figure 3.89	Suitable slope classes for groundwater recharging	112
Figure 3.90	Suitable soil classes for groundwater recharging	113
Figure 3.91	Stream layer for groundwater recharging	113
Figure 3.92	Suitable rainfall classes for groundwater recharging	114
Figure 3.93	ArcGIS Model to select most suitable locations for groundwater recharging	114
Figure 3.94	Groundwater Recharge Potential Map	115
Figure 3.95	Figure 3.95: Potential areas for rooftop water harvesting	117
Figure 4.1	Annual runoff in percentage of annual rainfall as a function of catchment size for small catchment (1 ha), medium-sized catchment (102 ha), and large catchment (104 ha)	118
Figure 4.2	Catchment BH	122
Figure 4.3	Catchment BE, BC and BD	122
Figure 4.4	Proposed locations for water harvesting structures in Suriyawewa	125

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF TABLES

Table 2.1	Advantages and disadvantages between using tank and cistern for water storage	7
Table 2.2	Reservoir capacity in Hambantota District	14
Table 2.3	Water Level of Hambantota Reservoirs (August 20 - August 26, 2001)	16
Table 2.4	Water Level of Hambantota Reservoirs (September 10 - September 16, 2001)	16
Table 2.5	Water Level of Hambantota Reservoirs (October 1- October 7, 2001)	17
Table 2.6	Persons Affected by the Drought by District (Information as at 27-08-2001)	17
Table 3.1	1:50,000 topographical sheets covering Hambantota District	19
Table 3.2	Degree of Slope and Percent of Slope Values of some slope angles	28
Table 3.3	Field Visit Locations	32
Table 3.4	Defined Slope classes for the Suriyawewa Terrain	72
Table 3.5	Head difference of the Seven Slope Classes	79
Table 3.6	h x Area Calculation for Catchment ab	81
Table 3.7	The thirty selected catchments which drain the highest amount of surface runoff according to the surface area and slopes	82
Table 3.8	Classification of Suriyawewa Rainfall Map	82
Table 3.9	Weights defined for the rainfall classes	84
Table 3.10	Weight X Area calculation for Catchment ‘ce’	87
Table 3.11	The fifteen catchments selected to harvest runoff water considering rainfall, slope and surface area.	87
Table 3.12	Calculation of the summation of (Surface area x h) values	102
Table 3.13	Preferable conditions selected for groundwater recharging	115
Table 4.1	Capacity calculation of the four selected points	119
Table 4.2	Runoff capacity calculations for Suriyawewa DS Area	120
Table 4.3	Capacity calculations for Andara Wewa	120
Table 4.4	Predicted Capacities of the tanks at the four selected locations	120

University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations