Multi-Criteria Decision Analysis in Land Suitability and Land Use Planning, Kadawedduwa Watershed, Nilwala River Basin, Sri Lanka

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INTRODUCTION

Land use is constantly changing due to both human activities and natural conditions, and can be understood as a conversion or a shifting from one use type to another, such as changes from agricultural to non-agricultural, or rural to exurban, suburban, or urban (Watson et al., 2000; Lambin and Meyfroidt, 2011; Eniyew, 2018; Sen, Gungor, and Sevik, 2018;). The type of land uses may also change such as the transition from rangeland to cropland, cropland to urban uses, or cropland to forest (FAO, 2016). Regional impacts may include loss of biodiversity, degradation of water or soil quality, or a decrease in primary productivity, any or all of which can adversely affect both natural and human systems (Aravinna et al., 2004a; Aravinna et al., 2004b; Khadka, 2012; Wang et al., 2014; Gyamfi et al., 2016). "Land is indeed one of the two vital resources of a country and one of the most complex in terms of its socio-economic, physical and environmental implications" (Perera, 1996).

On the island nation of Sri Lanka, rapid population growth in the country has resulted in greatly accelerated land use changes (Fernando, Stimers, and Lenegala, 2019), although the country remains largely agrarian and rural (Silva et al., 2007). In working to understand rural livelihood it is important to recognize how people use rural land; uses may change over time as a response to external or internal multi-dimensional triggers, and uses of land across rural populations may even vary from one household to the next (FAO, 1993). There are vast numbers of land use changes to be observed in Sri Lanka, some of which may be considered positive, and some detrimental to continued positive growth of economic systems, both in agriculture and industry. Empirical analysis and complex systems theory is not, however, typically applied to the uses for land in Sri Lanka as areas enter or alter modes of production. As is a common problem resulting from the current global climate change crisis, it is not the current generation that will be tasked with rectifying the effects of poor decision making, that responsibility is passed to future generations.

STUDY OBJECTIVES and AREA

Development of a land use plan for areas where future land use changes are likely to occur and consequently aid in decision making, planning, and implementing development projects is the primary focus of this study. Unplanned development brings about land use issues as well as environmental conflicts (Evans, Kirkpatrick, and Bridle, 2018). Within our study area, such unplanned activities are commonly undertaken, and as a result, residents in the Kadawedduwa sub-watershed are exposed with increasing frequency and magnitude to hazards and disasters such as mass movement events (typically landslides), flooding, drought, soil erosion and general degradation, and increased sedimentation of rivers. Further, the ecoregions of the area are adversely affected by land use alterations devoid of planning.

Using remote sensing (RS) and Geographic Information Systems (GIS), we construct a model to detect changes in land use patterns in the Kadawedduwa sub-watershed over the time period 2000 to 2014 (14 years). The model will assist in visualizing land use and land use change in this region. Land use planning is a natural resource management concept that has become increasingly important in Sri Lanka, as the government has developed large-scale plans, such as the Mahaweli and Upper Kotmale hydropower dams. Further, most land use plans are enacted based on political units; here we derive the land use plan based on physical geography, and as such, will be able to transfer the model application to other river basins in Sri Lanka.

We aim to answer the following overarching questions: 1) what are the optimal land use practices in the Kadawedduwa sub-watershed, and; 2) how should suitable land used for the Kadawedduwa sub-watershed be defined? Specifically, we aimed to prepare a land use plan that achieves the following objectives: 1) delineate the Nilwala River watershed area and Kadawedduwa sub-watershed area more accurately than currently-available maps; 2) update current land use maps and identify land use changes in the Kadawedduwa sub-watershed (2000-2014), and; 3) develop a land suitability map as well as a land use plan based on those findings.

The study area, located in south central Sri Lanka (Figure 1) is defined by 100315.38 m to 87562.55 m north and 176374.31 m to 188267.45 m east. Total surface area of the watershed is 8,825.29 ha covering 80 Grama Nilahardi divisions, eight divisional secretary divisions, and two districts, Matara and Hambantota, with the latter covering 8,107.1 ha (91.9 percent) and the former covering the remaining 718.19 ha (8.1 percent). The landscape varies from flat to rolling and undulating, with elevation ranging from 0.1 m to 213.27 m above mean sea level (MSL). Temperatures in the region range from an annual maximum of 33 ^{0}C (91.4 ^{0}F) to a minimum of 22 ^{0}C (71.6 ^{0}F.) The climate classification falls under tropical monsoon (*Am-Koeppen Geiger*), with an average annual rainfall of 2,169.84 mm (2.169 m, 7.12 ft). Agro-ecologically, the study area is comprised of two zones, Intermediate zone –Low country $_{1a}$ (IL_{1a}) and Intermediate Zone –Low country $_{1b}$ (IL1b). Soil types come in three major varieties: red-yellow podzolic (steeply dissected, hilly and rolling terrain), red-yellow podzolic (with soft or hard laterite; rolling and undulating terrain) and bog and half-bog soils (flat terrain). Land use patterns from the years 2000, 2008, and 2014 (Table 1, Figures 2-4) are dominated by home gardens (approximately 42 percent), paddies (approximately 18 percent), forests (approximately 15 percent), and rubber cultivation (approximately 10 percent). Of the total land area of 8825.29 ha, approximately 37 percent is cultivated in the year 2000, 39 percent in 2008 and finally, in 2014 it is shown to be 43 percent.

Land use type	**Extent (hectares)**		
	Year 2000	**Year 2008**	**Year 2014**
Built up areas	--	0.8	4.9
Home garden	3729.9	3762.2	3429.7
Tea	8.2	4.3	12.3
Rubber	1007.5	801.7	720.4
Coconut	359.8	455.1	397.3
Paddy	1643.3	1565.7	1567.0
Other field crops	209.0	631.9	1087.3
Forest	1272.1	1321.7	1401.2
Scrub	582.7	196.1	98.2
Water bodies	12.8	28.0	31.3
Other	--	57.8	75.7
Total	8825.3	8825.3	8825.3

Table 1: Land use data, 2000, 2008, and 2014.

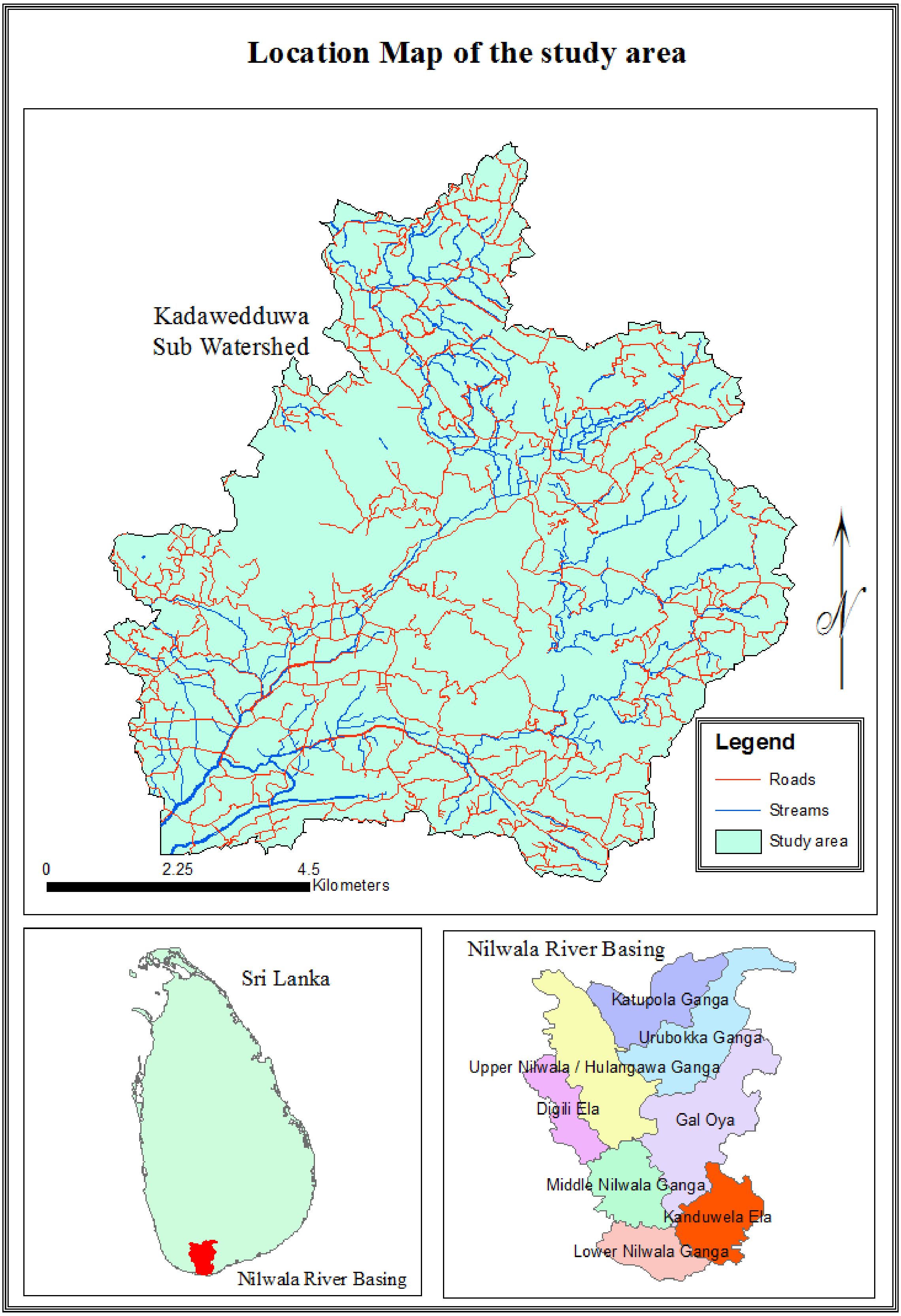

Figure 1: Study area.

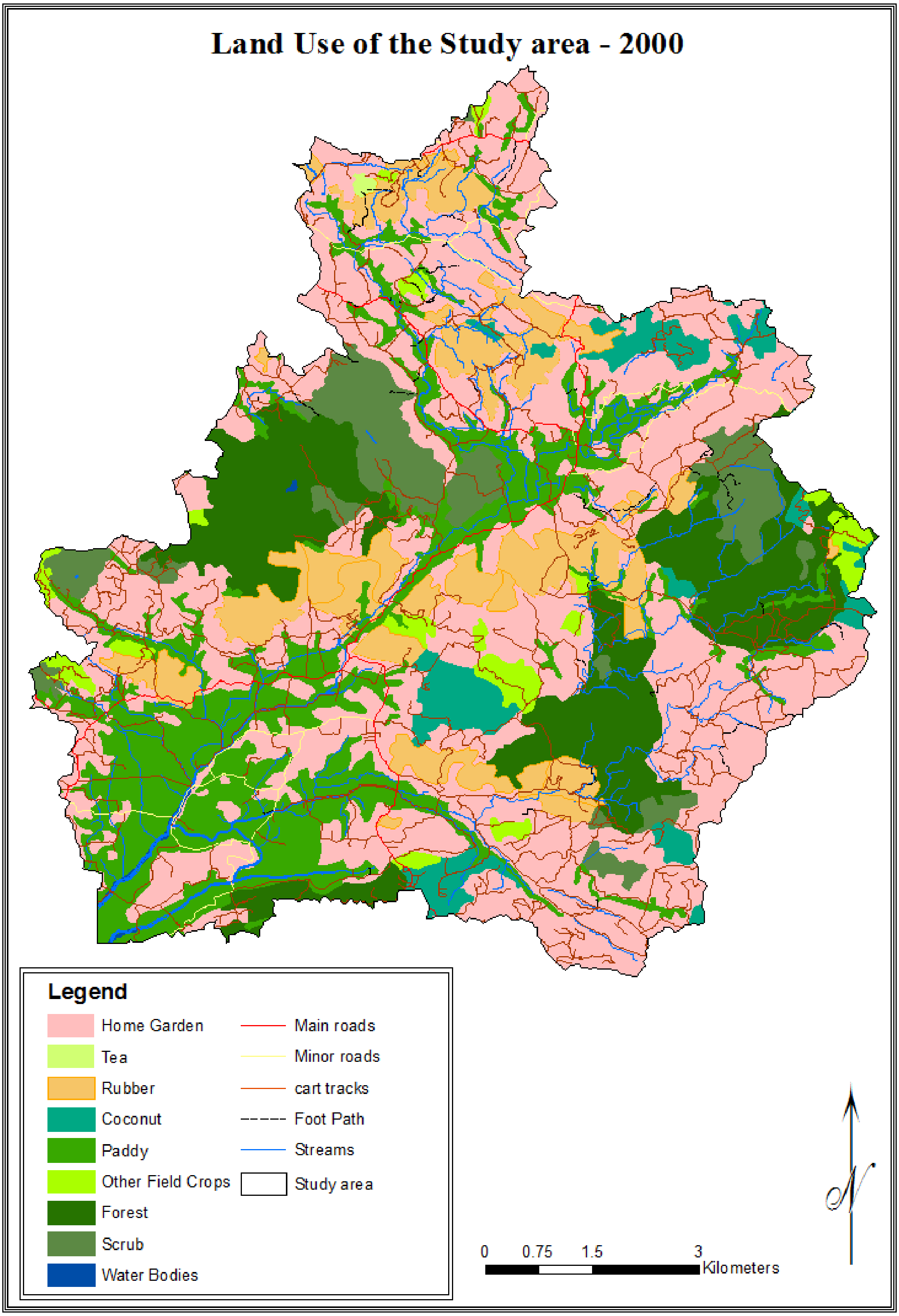

Figure 2: Land use, 2000.

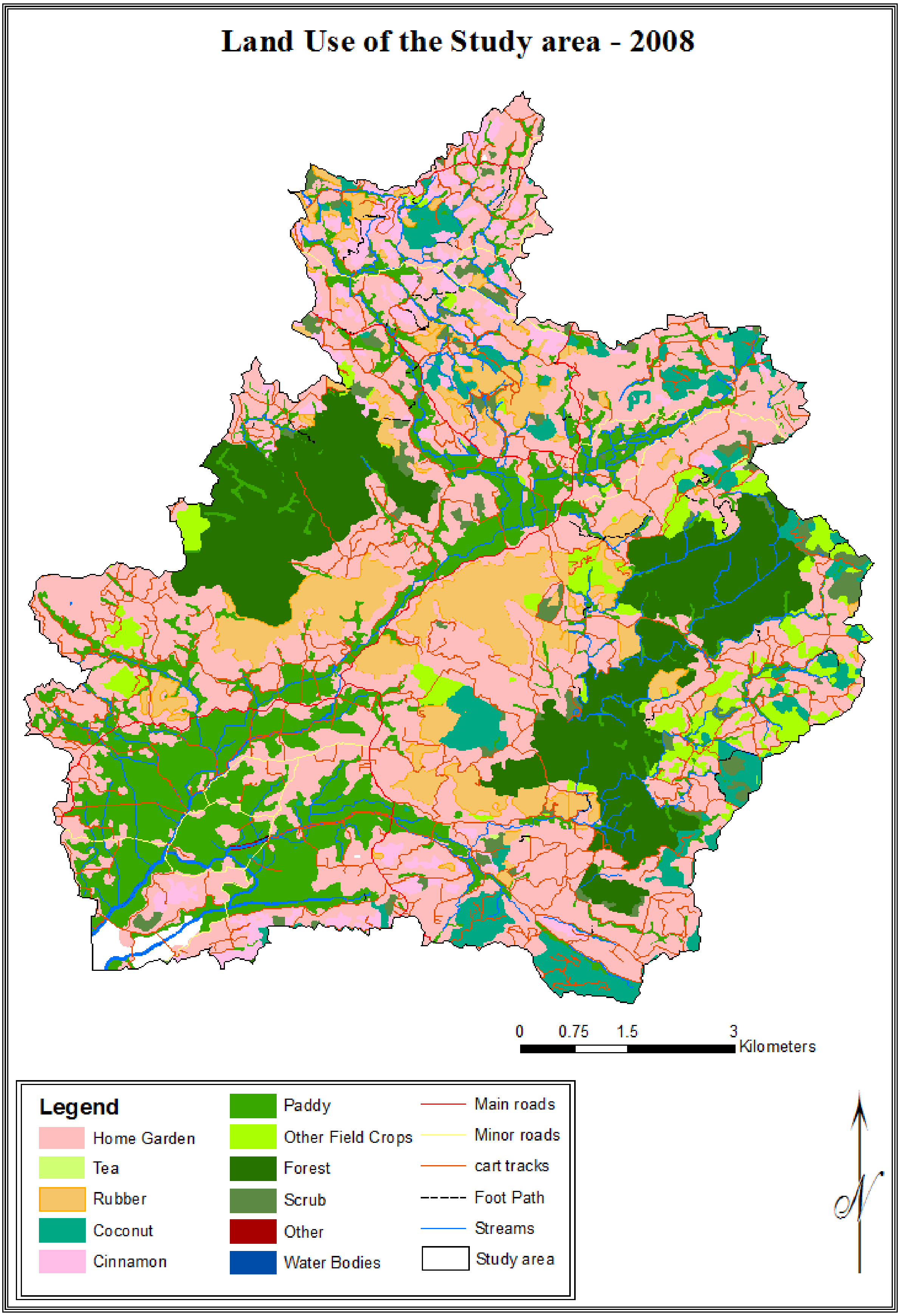

Figure 3: Land use, 2008.

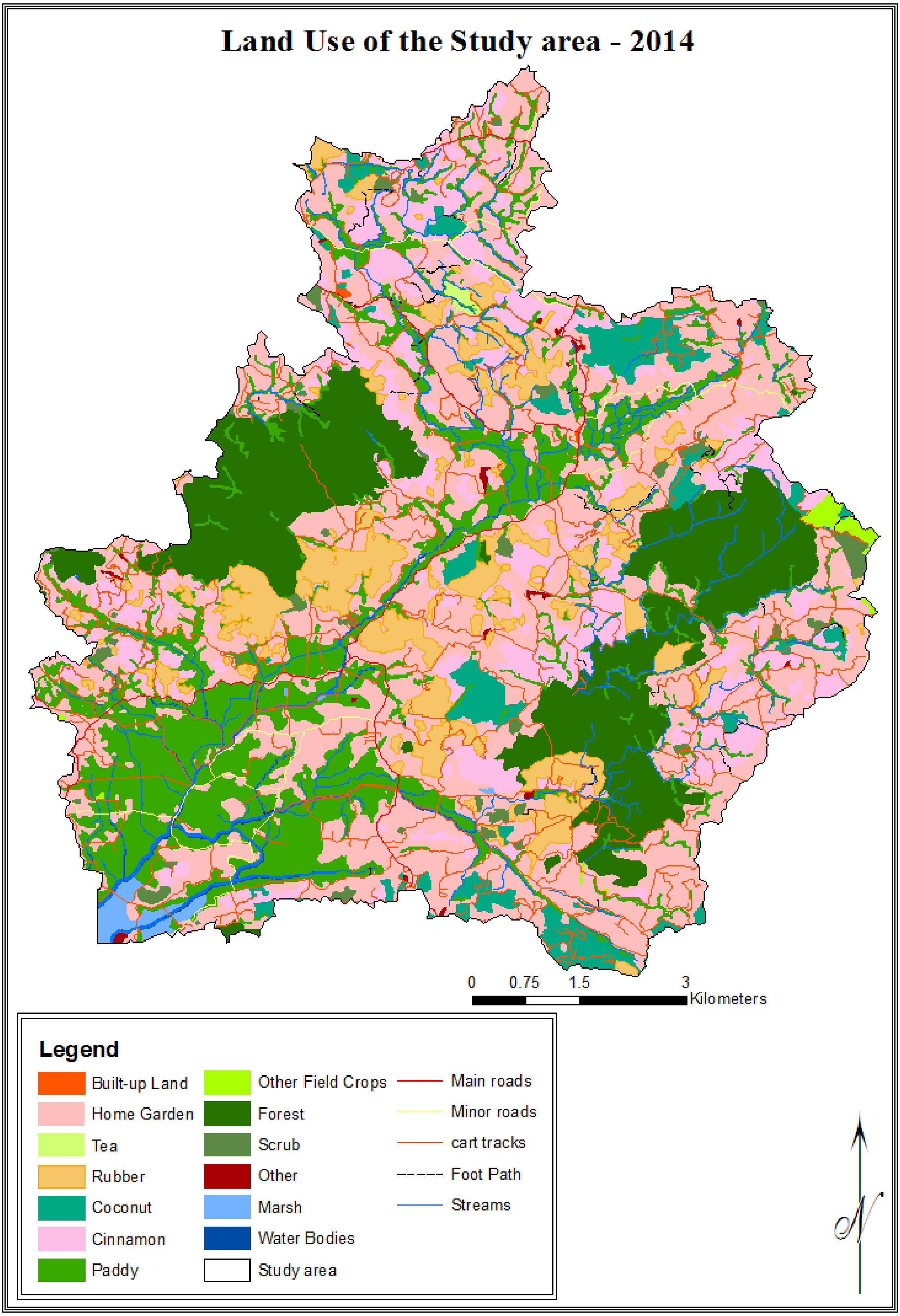

Figure 4: Land use, 2014.

METHODS

Data and Layers

In order to identify land use changes, we employ multi-criteria decision making (MCDA) to produce land use suitability maps, which allowed for the definition and recommendations for land use suitability within the study area. Under normal circumstances, land can be used for many purposes, including the categories we consider here: agricultural, housing, industry, forest or wildlife conservation, service, housing, service, animal husbandry, or tourism. We can approach a land suitability definition in two ways: 1) define the most suitable use of the land in a given area, or; 2) select the most suitable land given some pre-identified need/use for some land area (BLM, 2005). Here we use the first method in attempting to decide whether or not the Kadawedduwa sub-watershed is currently being used in the most optimal manner. It should be noted that regardless of the intended use, the methods to determine the most suitable land remain the same, it is the *a priori* intent that differs. Data layers used in this analysis are given in Table 2.

Map layer	Description
1) Slope	Using 5mx5m DEM
2) Soil depth	Sri Lanka soil map
3) Soil erosion	Land use with crop management + soil properties + slope
4) Soil texture	Sri Lanka soil map. (soil properties)
5) Drainage	Sri Lanka soil map. (soil properties)
6) Availability of rock	Land use map
7) Water availability	River layer buffer with suitable distance
8) Transportation	Road layer buffer with suitable way
9) Electricity	All areas are having equal opportunities
10) Telephone	All areas are having equal opportunities
11) Urban facilities	Selected service center buffer with suitable way
12) Neighbors	All areas are having equal opportunities
13)Environmental	(Not considered, but environmental impact is completed post-study)
14) Population	Population data layer

Table 2: Data layers used in this study.

Weights for these layers are derived from previous MCDA work, and are given in Table 3 below.

Criteria	Weight	Criteria	Weight
Environmental factor = 0.8920	*Soil = 0.1905* ***CR****= 0.7022*	Erosion	0.3120
		Soil hydrology	0.2020
		Soil depth	0.1650
		Soil structure	0.1650
		Soil texture	0.1550
	Land cover = 0.5096	Vegetation type	0.7098
		Vegetation density	0.2902
	Climate = 0.1231	Rainfall	0.5970
		Temperature	0.4030
	Topography = 0.1237	Slope	0.5890
		Elevation	0.4030
Economic factors = 0.1250	*Land use and avilability factors = 0.0531* *CR = 0.7270*	Land use	0.4032
		Distance from population centres	0.2984
		Distance from surface water	0.2984

Table 3: Weighting matrix for main criteria (after Jafari and Zaredar, 2010).

*CR=Consistency Ratio, given by

$$C.R. = \frac{C.I.}{R.I.}$$

where

$$C.I. = \frac{\lambda_{max} - n}{n - 1}$$

where

n = comparison items in the matrix
λ_{max} = largest Eigenvalue
R.I. = random consistency index

Next we delineate sub-watersheds of the Nilwala Ganga watershed by defining 5 m contour intervals, and utilizing a digital elevation model (DEM) in the Geographic Information System (GIS) platform ArcMap®, and applying the hydrology tool to the raster data to break the regions at discrete boundaries by hydrology rather than political units. We used the National Watershed Boundary Map to compartmentalize the sub-watersheds, shown below in Figure 5, with the before and after data displayed in Table 4.

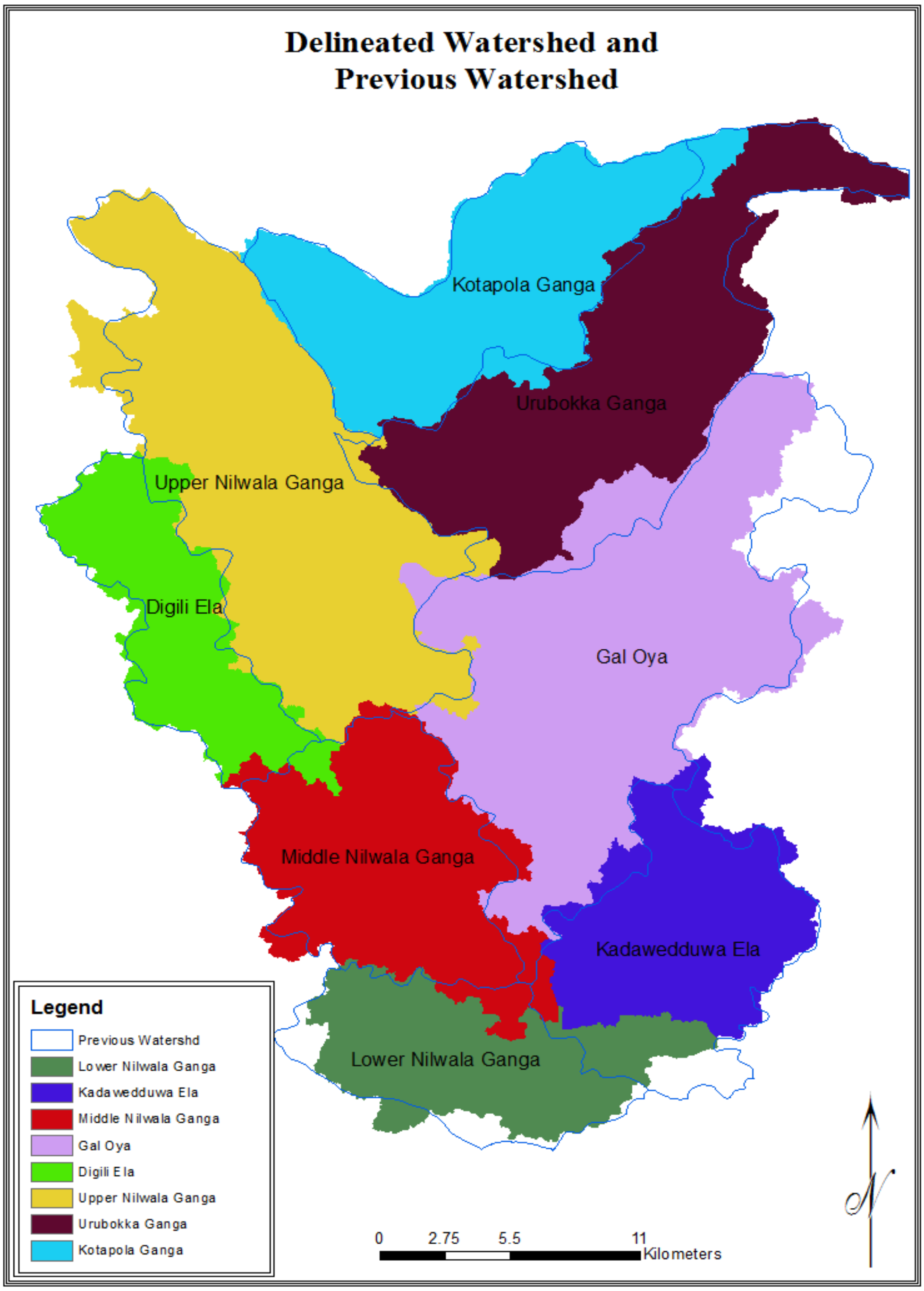

Figure 5: Watershed delineation and previous watersheds.

Sub watershed name	Extent (ha) according to the national watershed boundary map	Extent (ha) after delineation	Difference
Katupola Ganga	11513.00	12249.42	-736.42
Upper Nilwala / Hulangawa Ganga	18862.44	19226.86	-364.42
Urubokka Ganga	16561.82	14885.23	1676.59
Gal Oya	21481.34	20687.73	793.61
Digili Ela	6705.23	7421.46	-716.23
Middle Nilwala Ganga	9728.77	11154.68	-1425.91
Kadawedduwa Ela	10041.88	8825.29	1216.59
Lower Nilwala Ganga	7401.82	7649.73	-247.91
	102296.30	102100.40	195.90

Table 4: Data on Nilwala river basin and sub watersheds before and after delineation.

Soil erosion was less straightforward to include as a layer, and to fill this gap we produced a custom soil erosion map by weighted overlay and ranking of slope, land use with crop management, soil, and rain fall layers and data (Figures 6 and 7, Tables 5 and 6).

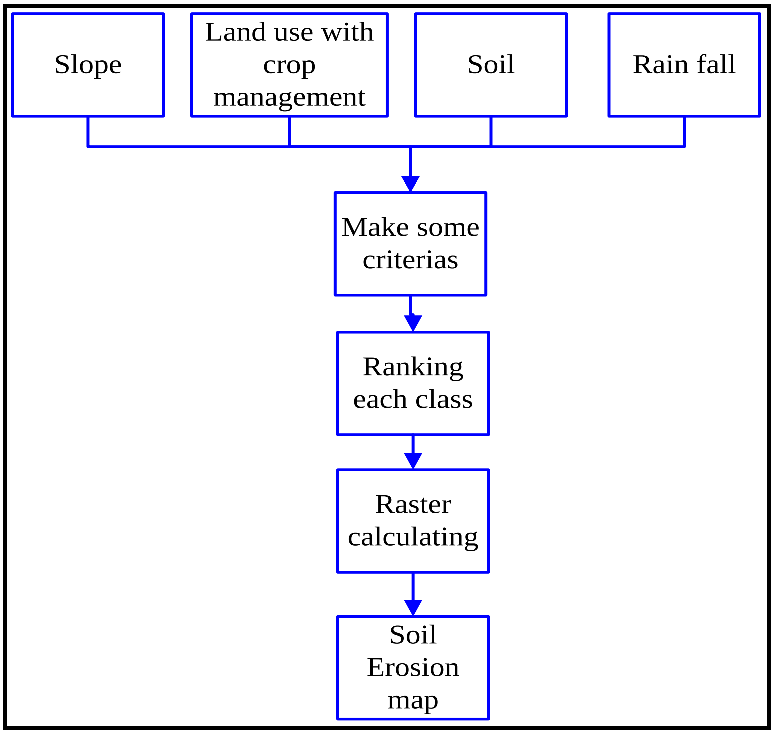

Figure 6: Weighted overlay scheme.

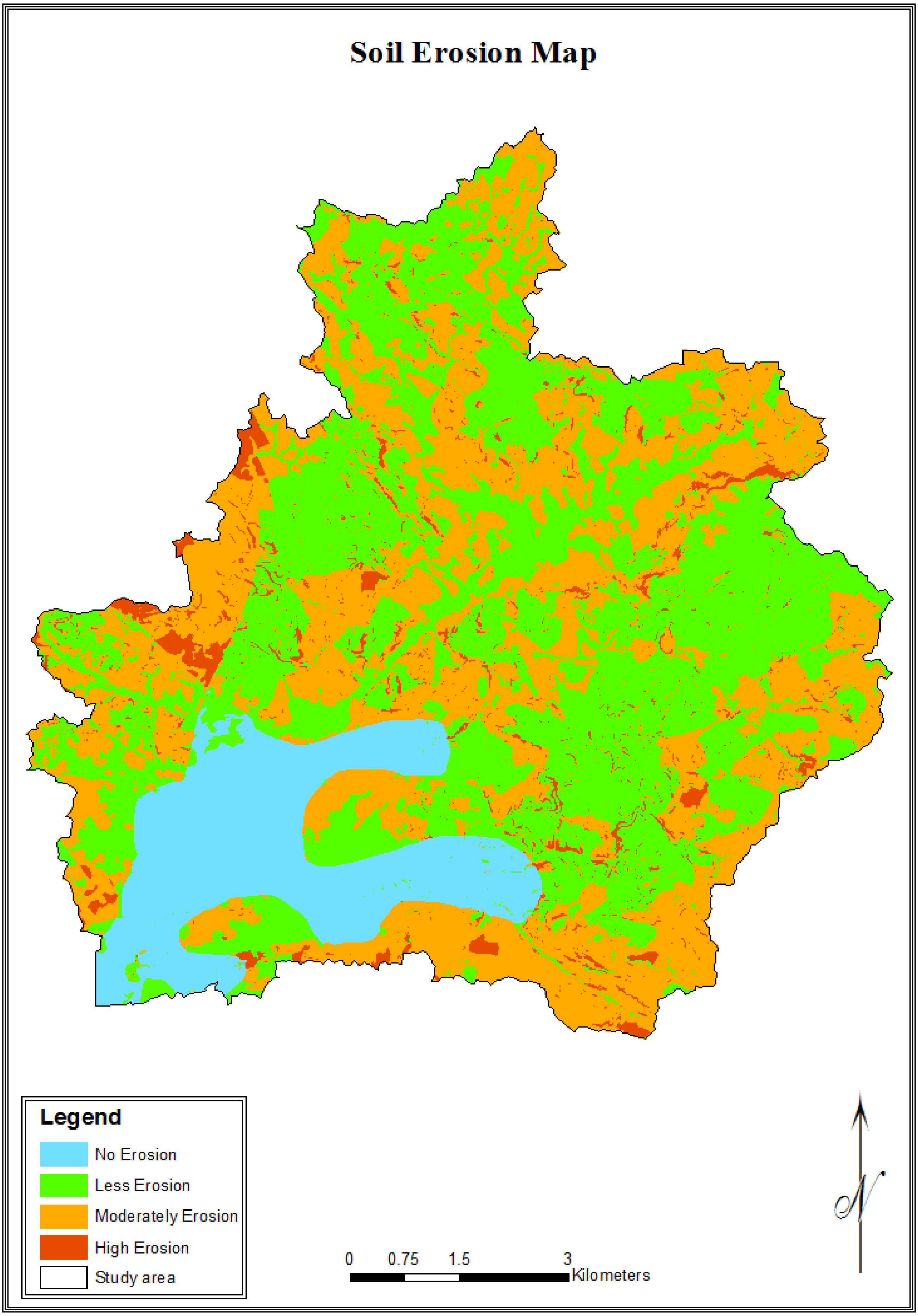

Figure 7: Soil erosion.

Data layer	criteria	Rank
Slope	60 <	3
	60- 45	2
	45	1
Land use data with crop management.	Poorly managed Rubber, Coconut and Cinnamon.	3
	Home garden, Moderately managed Tea, Rubber, Coconut, Cinnamon, Market garden, Scrub land, Barren land,	2
	Paddy, well managed Tea, Rubber, Water bodies and Play ground.	1
Soil	Red-Yellow Podzolic soils; steeply dissected, hilly and rolling terrain	3
	Red-Yellow Podzolic soils with soft or hard laterite; rolling and undulating terrain	2
	Bog and Half-Bog soils; flat terrain	1
Rainfall	1500<	3
	1500	2
	1250	1

Table 5: Soil erosion criteria and data layers ranking.

	More erosion	Less erosion	No erosion
Slope	3	2	1
Soil	3	2	1
Rain fall	3	2	1
Land use	3	2	1
Total	**12**	**8**	**4**

Table 6: Soil erosion classification by ranking using Jenks natural breaks.

Categorization of Land Use Changes

Attention was given to land use changes in order to identify patterns and trends, with the primary objective of the analysis focusing on changes between the years 2000, 2008, and 2014. We categorize the analysis of land into seven major categories, with the extent of land use changes over the same time displayed in Table 7 below.

1) Built-up areas
2) Agricultural lands/cultivation areas
3) Agricultural lands, paddy
4) Forest lands
5) Water bodies
6) Wetlands(boggy area)
7) Other lands

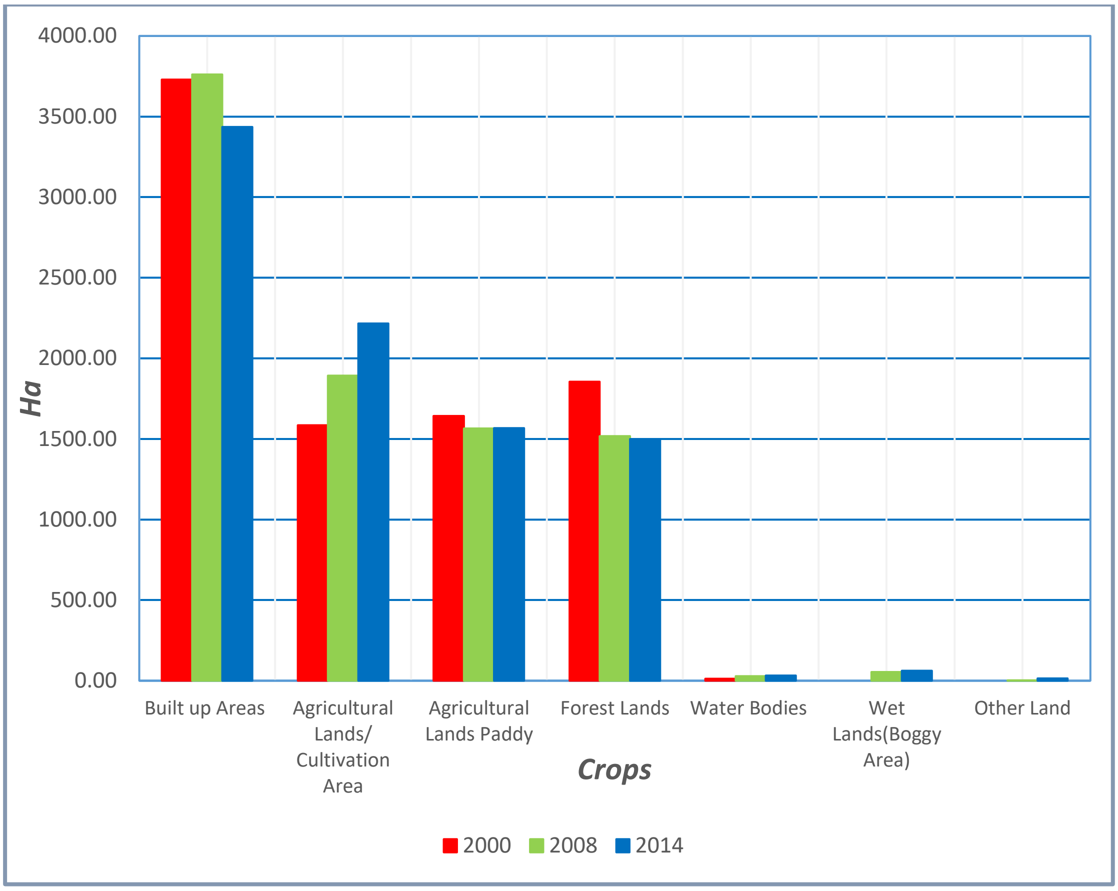

Figure 8: Figure Land use changes from 2000, 2008, and 2014.

Land use	yr2000	%	yr2008	%	yr2014	%
Built up areas	3729.91	*42.26*	3761.87	*42.63*	3434.57	*38.92*
Agricultural lands/cultivation area	1584.50	*17.95*	1893.38	*21.45*	2217.34	*25.12*
Agricultural lands, paddy	1643.31	*18.62*	1565.70	*17.74*	1567.00	*17.76*
Forest lands	1854.77	*21.02*	1517.87	*17.20*	1499.40	*16.99*
Water bodies	12.81	*0.15*	27.99	*0.32*	31.32	*0.35*
Wet lands (boggy area)			54.86	*0.62*	61.75	*0.70*
Other lands			3.62	*0.04*	13.90	*0.16*
Total	**8825.29**	***100.00***	**8825.29**	***100.00***	**8825.29**	***100.00***

Table 7: Land use in the years 2000, 2008, and 2014

RESULTS AND DISCUSSION

Selection of Protected Areas

A component of land use suitability identification is ensuring that protected areas are considered in the analysis, as to continue affording protections in place, or to better identify them for possible future conservation plans. In the study area, the following areas are presently considered: 1) forest reserves; 2) other state forests; 3) archaeological and historical reserves; 4) water bodies, and; 5) tourism and other developed areas. Field investigation of the study site revealed characteristics defining further areas in need of protection, and are considered as such in this research; they are: 1) coastal habitats; 2) currently unprotected forest lands; 3) areas prone to mass movement events (primarily landslides); 4) streams and surrounding riparian habitats that are not currently protected; 5) limnetic water bodies and immediately surrounding littoral zones which are not currently protected; 6) cultivated land (over

60 percent cultivated); 7) archaeological and historical sites which are not currently protected, and; 8) wetlands. The selection process for protected areas is a simple binary classification, 0 or 1, not protected or protected respectively (Table 8). The results of this exercise resulted in the areas defined as one of the two classes as displayed in Tables 9 and 10 below.

Protected area	Condition	Data source	Binary rank
Slope	Slope more than 60 percent	Slope map	0,1
Water bodies	All water bodies	Land use layer	0,1
Forest	Open forest, dense forest, Forest reserve, national park	Land use layer	
Marsh and Mangroves	All Marsh and mangroves	Land use layer	0.1
Archaeological sites	365.76 meters around the location (400 yards)	Archaeological	0,1
Water holes	25 meters around places	Water holes	0,1
Streams 1st	25 meters	Stream line	0,1
Streams 2nd	10 meters	Stream poly.	0,1

Table 8: Ranking for selected protected areas.

	Binary ranking	Extent (Ha)
Protected area	1	2955.13
Balance area	0	5869.91
Total		**8825.04**

Table 9: Protected areas, total (ha).

Data layers	Binary ranking	Extent (ha)	Total area extent (Ha)
Main streams (S1)	1	100.49	
	0	100.49	
	Total		***200.98***
Miner stream (S2)	1	323.201	
	0	8502.094	
	Total		***8825.295***
Water holes	1	28.087	
	0	8797.208	
	Total		***8825.295***
Archaeological sites	1	831.927	
	0	7993.368	
	Total		***8825.295***
Forest	1	1401.202	
	0	7424.094	
	Total		***8825.296***
Mash and mangroves	1	61.754	
	0	8763.542	
	Total		***8825.296***
Water bodies	1	31.324	
	0	8793.972	
	Total		***8825.296***
Slope > 60	1	604.795	
Slope < 60	0	8220.468	
	Total		***8825.263***

Table 10: Areas which should be protected according to layer.

Land Use Identification

Identification of suitable land use for a given area is a major undertaking, and there are myriad methods available to the planner in order to execute successful planning and analysis; here we explain the methods used for the types of land use described in the *Methods* section. We begin with identifying suitable areas for agricultural land use.

Identification of Suitable Land for Agriculture

Each layer is zoned for four categories: 1) highly suitable, moderately suitable; marginally suitable, or; not suitable; and assigned an integer of 4, 3, 2, 1, for each area respectively. The ranking and weight criteria for suitable agricultural land is given in Table 11 with the results of the weighting shown in Table 12. Figures 9 and 10 display the results of the classification in the GIS based on these weights. In order to determine suitability we use the formula created by Hofstee (1997), which is given by:

Agriculture Suitability Lands = ("Slope" * 0.589) + ("Soil depth" * 0.165) + ("Soil Erosion" * 0.312) + ("Soil texture" * 0.155) + ("Drainage" * 0.202) + ("Rocky Soil" * 0.165) + ("Water availability" * 0.2984) + ("Transportation condition" * 0.125)

Criteria	**1st Stage (4) - S1 Highly suitable**	**2nd Stage (3) - S2 Moderately suitable**	**3rd Stage (2) - S3 Marginally suitable**	**4th Stage (1) - N Not suitable**	**Layer**	**Weight**
Slope	0-30%	30-40%	40-60%	>60%	Slope layer	0.589 Slope
Soil depth	Very deep (>120 cm	Deep (90 cm-120cm)	Moderate (9cm – 3cm)	No depth (cm <3)	Soil layer	0.165 Soil depth
Soil Erosion	No erosion	Marginal erosion	Moderate erosion	High erosion	Soil erosion layer	0.312 Erosion
Soil texture	Loma soil	Moderately sandy	Sandy Soil	Pebbles with sandy soil	Soil layer	0.155 Soil texture
Drainage	Well drained	Moderately drained	Partially drained	Poor drained	Soil layer	0.202 Soil hydrology
Rockiness Soil	No	Partially rock	Moderately rock	High rock	Land use Layer	0.165 Soil structure
Water availability	Inside land	Near land	In possible distance	Not available	River layer buffer 25m, 50m, 200m more than 200m	0.2984 Distance from surface water
Transportation condition	Available	Closely available	Not available. Can develop	Not available	Road layer buffer 25m, 50m, 100, more than 100	0.125 Economic factors

Table 11: Ranking and weight criteria for suitability of lands for agriculture.

Criteria	**Weight**	**Fist rank**				**Multiply by weight**			
		Highly suitable	Moderately suitable	Marginally suitable	Not suitable	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
Slope	0.589	4	3	2	1	2.36	1.77	1.18	0.59
Soil depth	0.165	4	3	2	1	0.66	0.50	0.33	0.17
Soil Erosion	0.312	4	3	2	1	1.25	0.94	0.62	0.31
Soil texture	0.155	4	3	2	1	0.62	0.47	0.31	0.16
Drainage	0.202	4	3	2	1	0.81	0.61	0.40	0.20
Rockery Soil	0.165	4	3	2	1	0.66	0.50	0.33	0.17
Water availability	0.298	4	3	2	1	1.19	0.90	0.60	0.30
Transportation condition	0.125	4	3	2	1	0.50	0.38	0.25	0.13
		32	24	16	8	**8.05**	**6.03**	**4.02**	**2.01**

Table 12: Ranking and given weight for suitability of lands for agriculture.

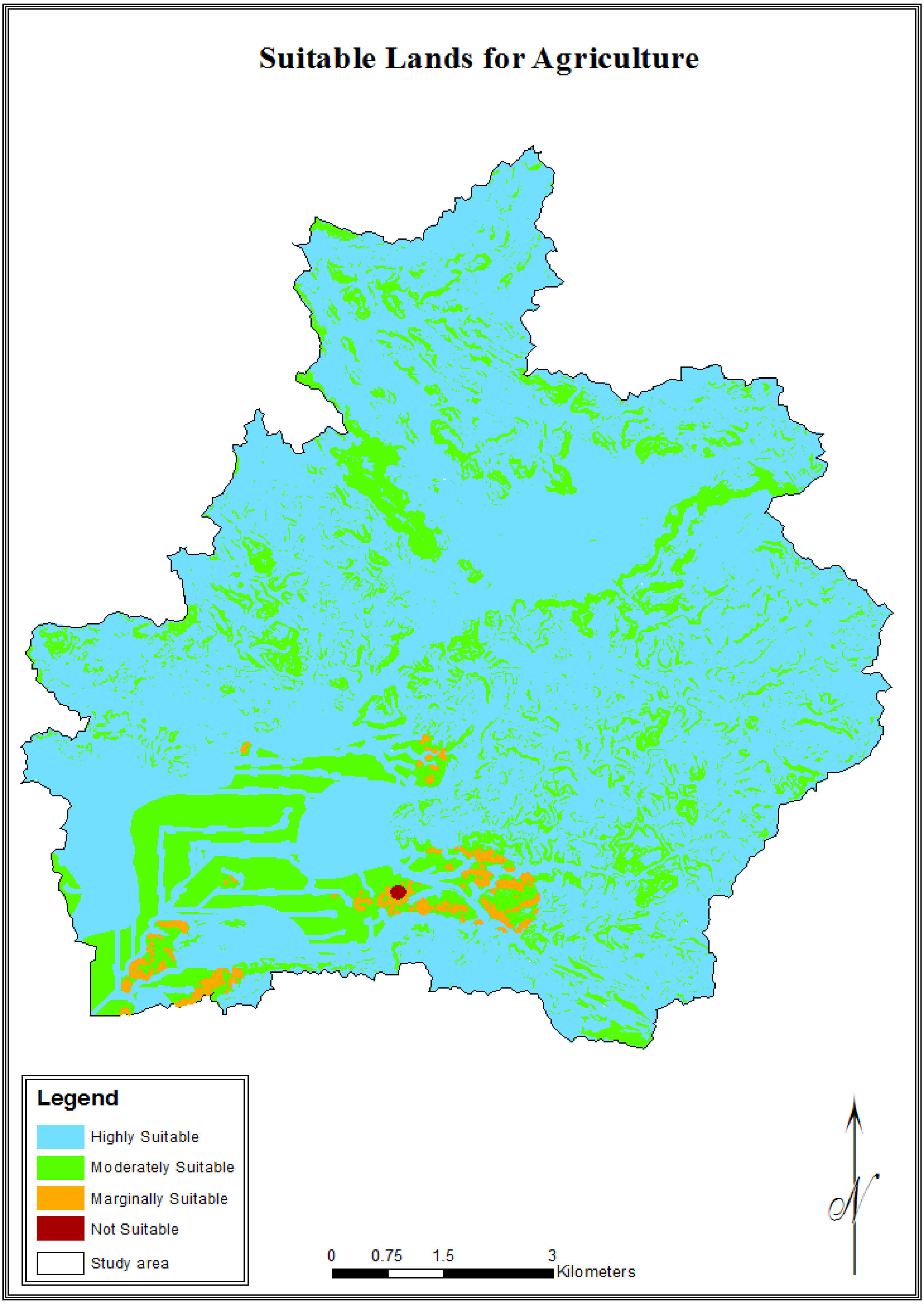

Figure 9: Suitable lands for agriculture.

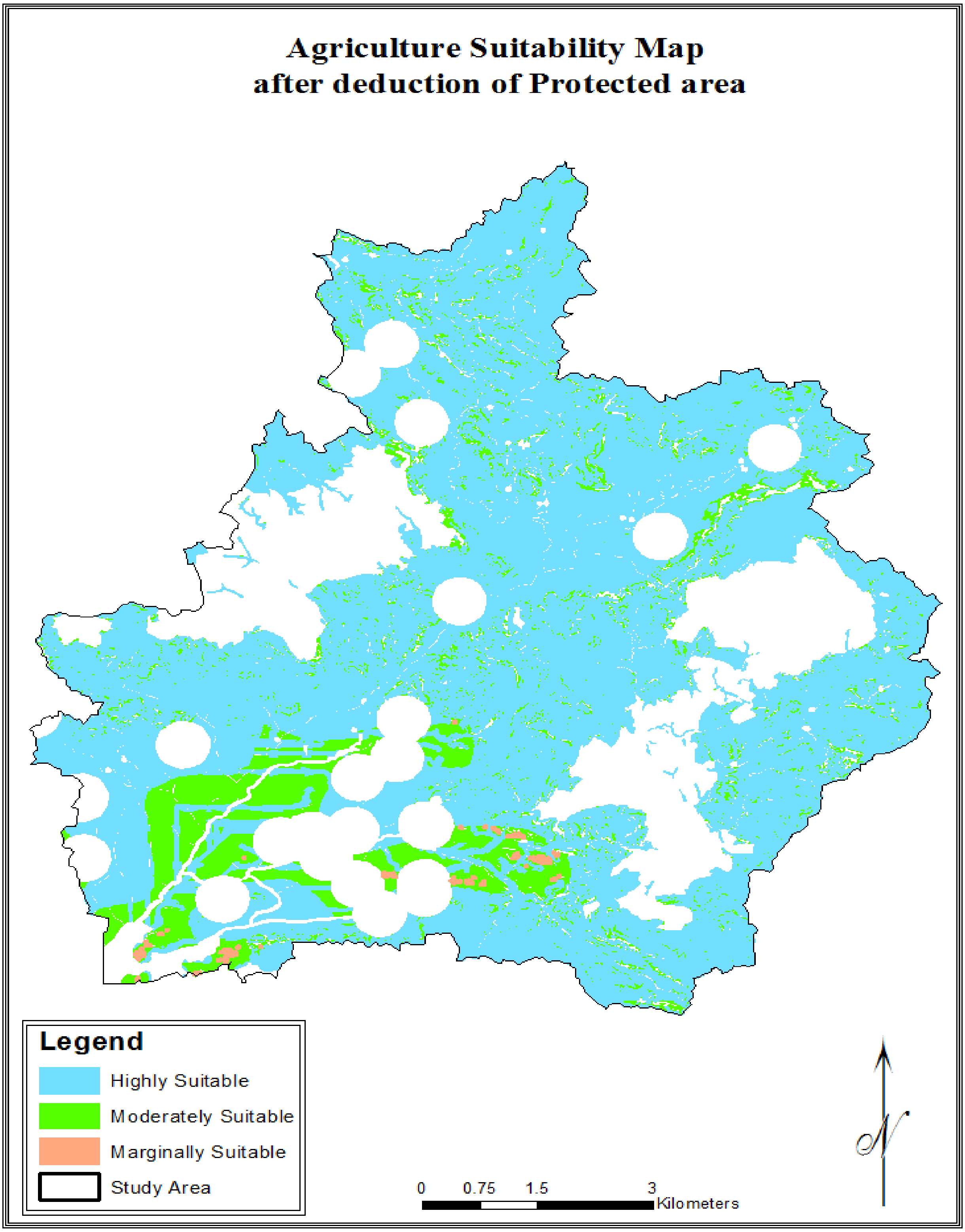

Figure 10: Agriculture suitability map after deduction of protected area.

Suitable classes	Area (Ha)
Highly suitable	4705.02
Moderately suitable	1163.42
Marginally suitable	1.73
Protected	2955.13
Total	**8825.29**

Table 13: Suitable agricultural area in hectares based on this analysis.

Identification of Suitable Land for Residential Purposes

Here we apply the method again to determine suitable areas for residential purposes, using Hofstee's formula (1997), given by:

Residential Suitability Lands= ("Water availability" * 0.2984) + ("Electricity" * 0.125) + ("Telephone" * 0.125) + ("Unban facilities" * 0.125) + ("Neighbors" * 0.2984) + ("Slope" * 0.589) + ("Drainage" * 0.202) + ("Rocky Soil" * 0.165)

We identify, rank and weight the suitability for residential purposes, shown in Tables 14 and 15:

Criteria	**1st Stage 4 - S1 Highly Suitable**	**2nd Stage 3 - S2 Moderately Suitable**	**3rd Stage 2 - S3 Marginally Suitable**	**4th Stage 1 - N Not Suitable**	**Layer**	**Weight**
Water availability	Inside land	Near land	In possible distance	Not available	River layer buffer 25m, 50m, 200m more than 200m	0.2984 Distance from surface water
Electricity	Inside land	Near land	In possible distance	Not available	All area have electricity.	0.125 Economic factors
Telephone	Inside land	Near land	In possible distance	Not available	All area have telephone facilities.	0.125 Economic factors
Unban facilities	Within 01 k	Within 10 km	Within 20 km	20 km away	Service centers layer	Economic factors= 0.125
Neighbors	Very good	Good	Moderately	Satisfactory	All area have same equality.	0.2984 Distance from population
Slope	Less than 60%			More than 60%	Slope	0.589 Slope
Drainage	Can arrange			Can't arrange	Soil layer	0.202 Soil hydrology
Rockiness	Can build			Can't build	Land use layer	0.165 Soil structure

Table 14: Ranking and weight criteria for suitability of lands for residential purposes.

Criteria	**Weight**	**Fist ranking**				**Multiply by weight**			
		Highly suitable	Moderately suitable	Marginally suitable	Not suitable	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
Water availability	0.2984	4	3	2	1	1.19	0.90	0.60	0.30
Electricity	0.125	4	3	2	1	0.50	0.38	0.25	0.13
Telephone	0.125	4	3	2	1	0.50	0.38	0.25	0.13
Unban facilities	0.125	4	3	2	1	0.50	0.38	0.25	0.13
Neighbors		-	-	-	-	0.00	0.00	0.00	0.00
Slope	0.589	4	3	2	1	2.36	1.77	1.18	0.59
Drainage	0.202	4	3	2	1	0.81	0.61	0.40	0.20
Rockiness	0.165	4	3	2	1	0.66	0.50	0.33	0.17
		28	21	14	7	**6.52**	**4.89**	**3.26**	**1.63**

Table 15: Ranking and given weight for suitability of lands for residential purposes.

Suitable class	**Area (Ha)**
Highly suitable	5869.63
Protected	2955.66
Total	8825.29

Table 16: Suitable residential area in hectares based on this analysis.

The results of the residential analysis shown in Figure 11, as well as the totals displayed in Table 15, identify areas well-suited to residential uses, with protected areas excluded in Figure 12.

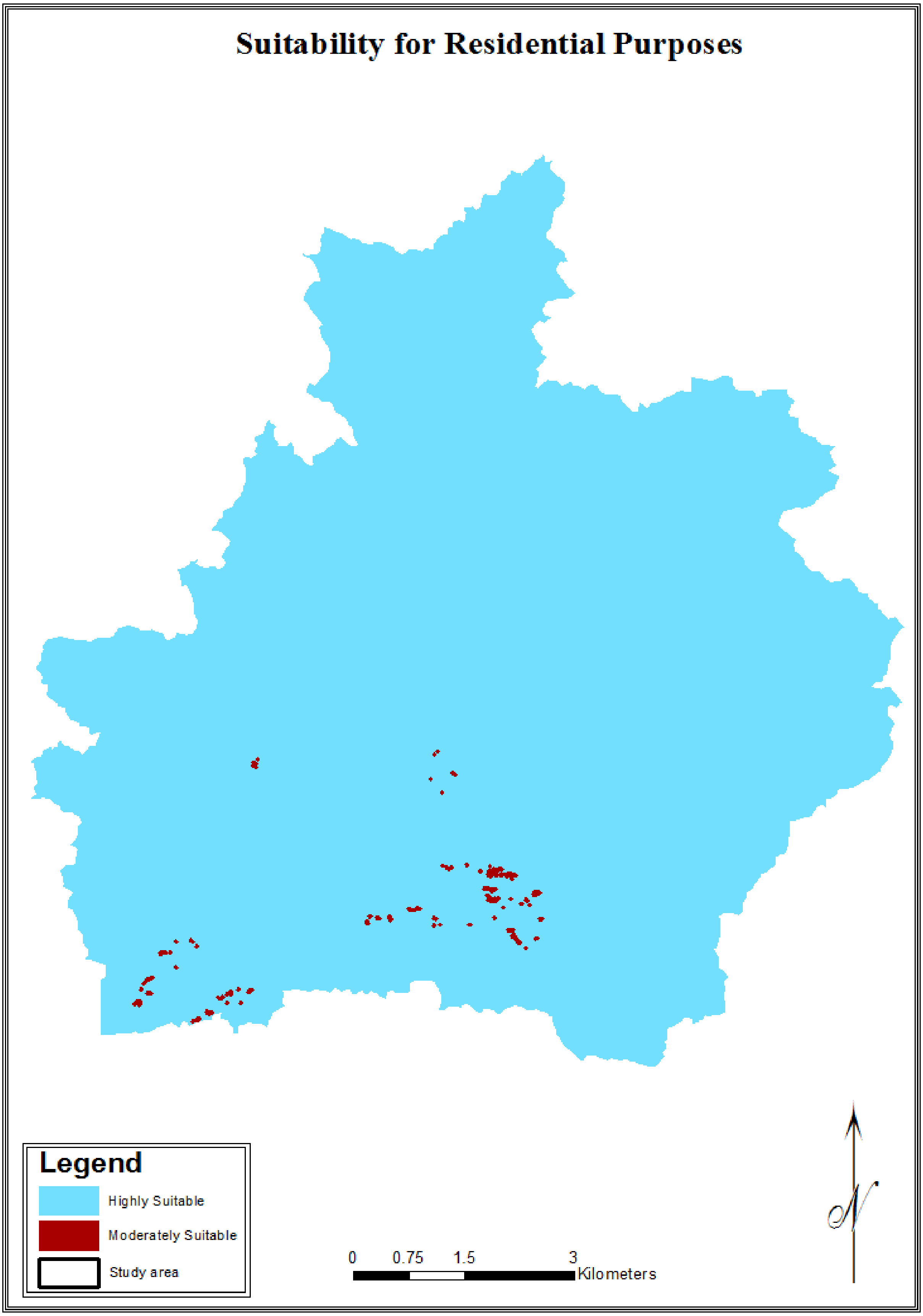

Figure 11: Map showing suitability for residential purposes.

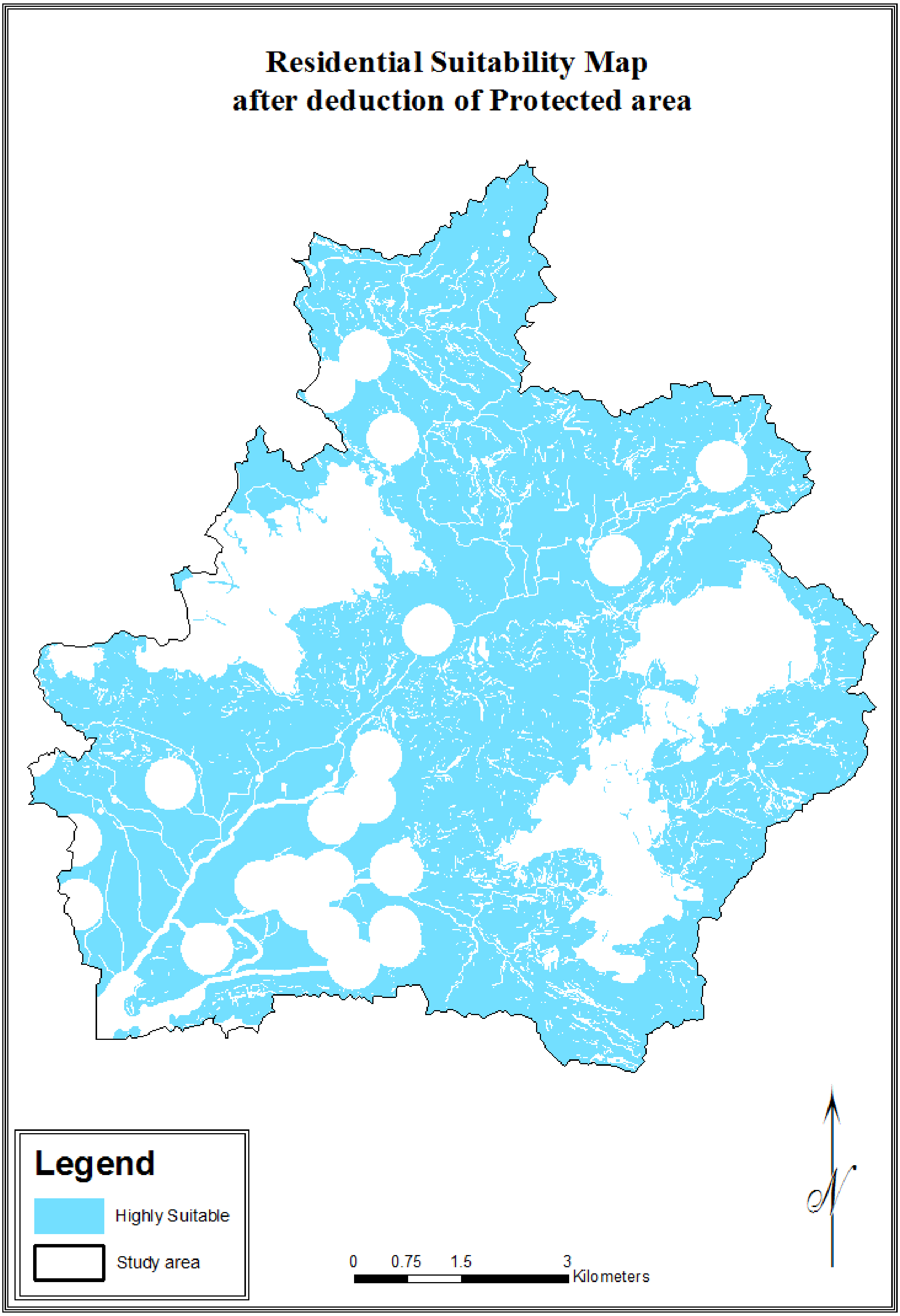

Figure 12: Residential suitability map after deduction of protected area.

Identification of Suitable Land for Industry

For industrial use, we continue with the methods described, and again use a formula created by Hofstee (1997) to utilize considerations in determining suitability, given by:

Industrial Suitability Lands = (“Water availability”* 0.2984) + (“Electricity” * 0.125) + (“Telephone * 0.125”) + (“Transportation * 0.125”) + ("Population" * 0.2984) + ("Facilities for workers" * 0.125) + ("Slope" * 0.589) + ("Drainage" * 0.202) + ("Rockery Soil" * 0.165) (Figures 13 and 14)

Criteria	**1st Stage 4 - S1 Most suitable**	**2nd Stage 3 - S2 Suitable**	**3rd Stage 2 - S3 Less suitable**	**4th Stage 1 - N Not suitable**	**Layer**	**Weight**
Water availability	Inside Land	Near Land	In possible distance	Not possible	River layer buffer 25m, 50m, 200m more than 200m	0.2984 Distance from surface water
Electricity	3-phase	Proposed 3-phase	Difficult for 3-phase	Not possible	All area have same equality.	0.125 Economic factors
Telephone	Inside land	Near land	In possible distance	Not possible	All area have same equality.	0.125 Economic factors
Transportation	Available to the land	Closely available	Not available. Can develop	Not possible	Road layer buffer 25m, 50m, 100, more than 100	0.125 Economic factors
Environmental effect after factory started	There is no any ecological effects	There is minor effect	Problems can be arise. But they can be solve by planning properly	Ecological effect is a very sensitive case	After decide industry should be check	
Population	No population	Less population	Moderately population	High population	Population density	0.2984 Distance from population centers
Facilities for workers	Within 01 km	Within 10 km	Within 20 km	20 km away	Service centers layer	0.125 Economic factors
Slope	Less 60%			More than 60%	Slope layer	0.589 Slope
Drainage	Can arrange			Can’t arrange	Soil layer	0.202 Soil hydrology
Rockiness	Can build			Can’t build		0.165 Soil structure

Table 17: Ranking and weight criteria for suitability of lands for industry.

Criteria	Weight	Fist ranking				Multiply with weight			
		Highly suitable	Moderately suitable	Marginally suitable	Not suitable	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
Water availability	0.2984	4	3	2	1	1.19	0.90	0.60	0.30
electricity	0.125	4	3	2	1	0.50	0.38	0.25	0.13
Telephone	0.125	4	3	2	1	0.50	0.38	0.25	0.13
Transportation	0.125	4	3	2	1	0.50	0.38	0.25	0.13
Environmental effect after factory started	--					0.00	0.00	0.00	0.00
Population	0.2984	4	3	2	1	1.19	0.90	0.60	0.30
Facilities for workers	0.125	4	3	2	1	0.50	0.38	0.25	0.13
Slope	0.589	4	3	2	1	2.36	1.77	1.18	0.59
Drainage	0.202	4	3	2	1	0.81	0.61	0.40	0.20
Rockiness	0.165	4	3	2	1	0.66	0.50	0.33	0.17
		40	30	20	10	8.21	6.16	4.11	2.05

Table 18: Ranking and given weight for suitability of lands for industry.

Suitable Class	Area (Ha)
Highly suitable	5867.62
Moderately suitable	2.02
Protected	2955.66
Total	8825.29

Table 19: Suitable industrial area in hectares based on this analysis.

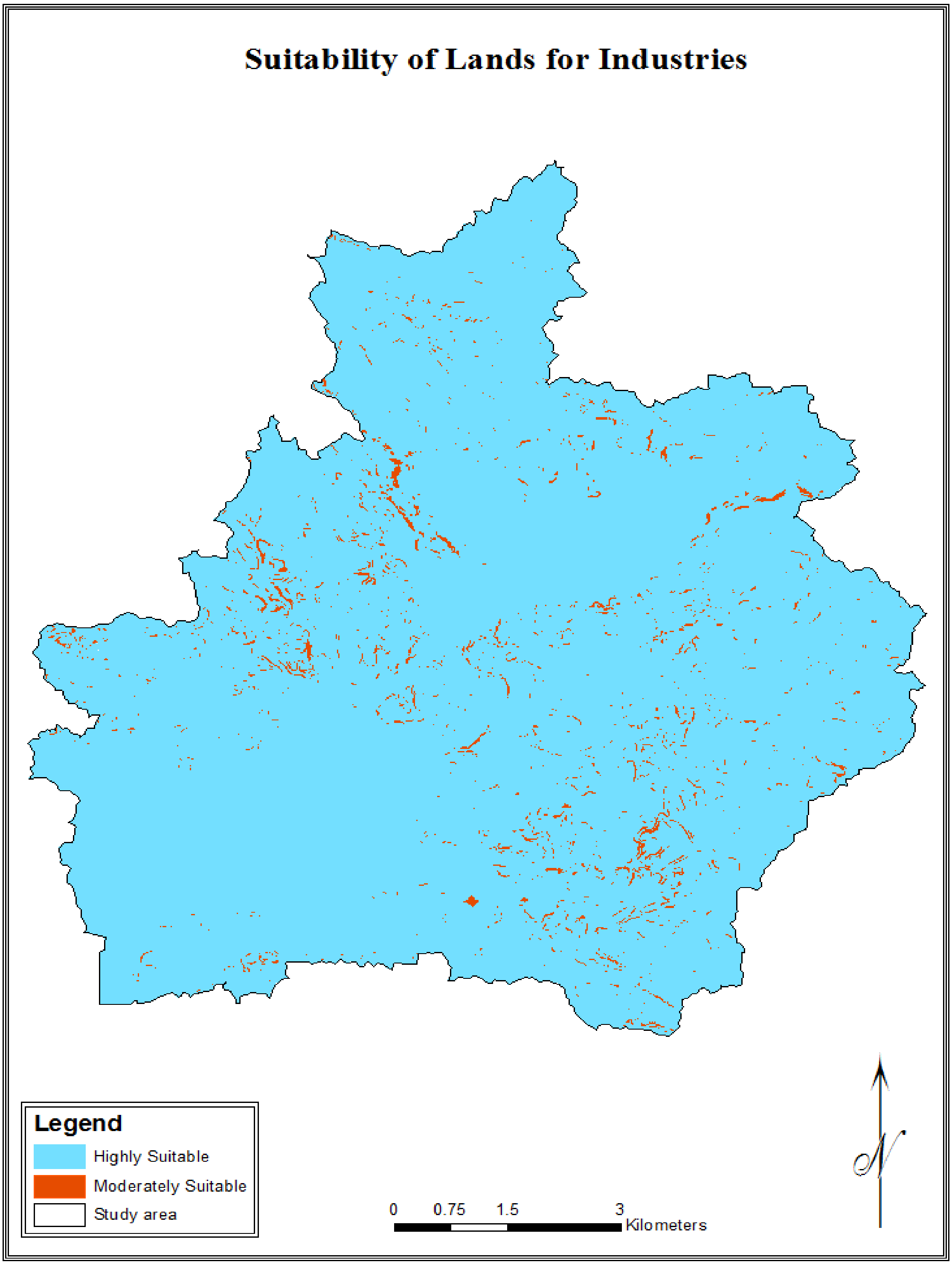

Figure 13: Suitability of lands for industries.

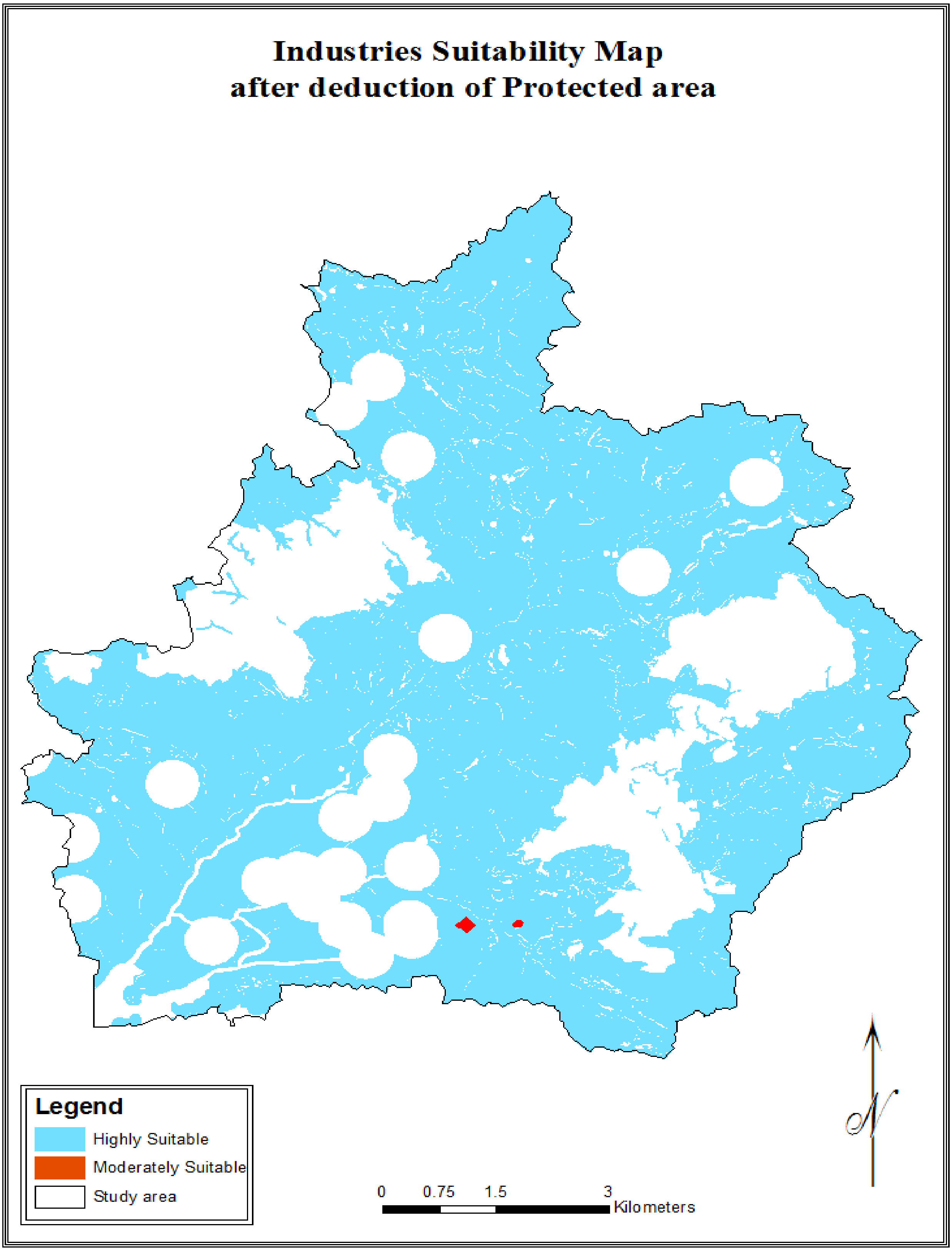

Figure 14: Industries suitability map after deduction of protected area.

When researching land use changes in the study area the first stage is to identify the most important existing topological, environmental, and physical features on the limited research area. This research has identified the specific limited extent as protected area. And primmest attention has considered to following features such as Forest reserves, other state forests, Archaeological and historical reserves, Water bodies, Tourism development areas. Field investigation has revealed few extra hidden issues other than above considered protected features. Such as costal natural habitats, forest areas which are not presently protected, land slide prone areas, streams which are not presently protected, lakes and tanks which are not presently protected, cultivated lands over 60%, archeological and historical places which are not presently protected, and wet lands. During the protected area analysis process, we have used binary logical method for each layer and selected the areas which should be protected. After the calculation and conversion process all the protected areas have identified, 2955.125 hectares were identified as total protected areas including forest, marsh and water bodies, 1195.78 hectares were used for human activities from the total protected area. Based on the calculation and analysis we have created the protected area map and have given binary ranking 1 for protected area and 0 for rest of the area; when we calculate the whole land area, the extent is approximately 8825.04 hectares.

According to the suitability analysis we find three suitability classes: highly suitable, moderately suitable, and marginally suitable. Agriculture lands are very important, due to the fact that houses or industries can be established in any area without natural hazards, but for agriculture purposes, we should attend to more factors. Table 19 land use areas by representing them with the symbols BUL, GI, PL, as land use type in the area and the proposed recommendation of highly suitable for agriculture. As the recommendations of the research has identified, present use can be continued, that land use is suitable for residential purpose, and the T1w, C1w, C2w, R1w, R2w land use types are recommended for agriculture areas where present use can be continued. Maintenance of the maximum crop cover and present management level should continue. Results also recommend continuing land use practice and the area should be conserved for T2m, C1m, C2m, R1m, R2m, OP1m, OP7m, G2. Following C1p, C2p, R1p, R2p, R3, OP1p, agriculture areas were improving the productivity of present crop land. Therefore, the research introduces this as an appropriate practice in the suitable area. P1, P2 areas are where can be continued for agriculture purpose as present practice. But P4, land use type paddy and other crops, the research recommends continuing while attending to irrigation problems. Scrub and barren land are recommended to be introduced for appropriate use; Table 19 identifies highly suitable areas for agricultural. After the selection of protected areas and agricultural areas, residential areas can be selected from the remaining area excluding natural hazards. From the areas which are suitable for agriculture, we can find present residential lands and these lands cannot be recommended for agriculture (Table 20).

Symbol	Land use type	Area (Ha)	Recommendations
BUL	Built-up land	1.56	Present use can be continued. Suitable for residential purposes
G1	Home garden	2199.60	Present use can be continued. Suitable for residential purposes
PL	Play ground	0.63	Present use can be continued. Suitable for residential purposes
T1w	Seeding tea (Well managed)	0.48	Agriculture areas where present use can be continued. Maintenance of the maximum crop cover and present management level
T2m	V.P.Tea (Moderately managed)	7.92	Agriculture areas where present use can be continued with conservation practices
C1w	Coconut monocrop (Well managed)	173.34	Agriculture areas where present use can be continued. Maintenance of the maximum crop cover and present management level
C1m	Coconut monocrop (Moderately managed)	78.99	Agriculture areas where present use can be continued with conservation practices
C1p	Coconut monocrop (Poorly managed)	9.72	Agriculture areas where improving the productivity of present crop land. Introduce appropriate uses
C2w	Coconut intercrop (Well managed)	42.77	Agriculture areas where present use can be continued. Maintenance of the maximum crop cover and present management level
C2m	Coconut intercrop (Moderately managed)	7.48	Agriculture areas where present use can be continued with conservation practices

Table 20: Proposed land use changes in highly agricultural suitable areas

Symbol	Land use type	Area (Ha)	Recommendations
BUL	Built-up land	1.66	Present use can be continued. Suitable for residential purposes
G1	Home garden	2758.59	Present use can be continued. Suitable for residential purposes
PL	Play ground	0.63	Present use can be continued. Suitable for residential purposes
T1w	Seeding tea (Well managed)	0.01	Present use can be continued. Maintenance of the maximum crop cover and present management level
T2m	V.P.Tea (Moderately managed)	0.11	Present use can be continued. Suitable for residential purposes
R1w	Rubber monocrop (Well managed)	4.22	Present use can be continued. Maintenance of the maximum crop cover and present management level
R1m	Rubber monocrop (Moderately managed)	0.42	Present use can be continued. Suitable for residential purposes
R1p	Rubber monocrop (Poorly managed)	0.01	Present use can be continued. Suitable for residential purposes
R2w	Rubber intercrop (Well managed)	0.13	Present use can be continued. Maintenance of the maximum crop cover and present management level
R2m	Rubber intercrop (Moderately managed)	0.21	Present use can be continued. Suitable for residential purposes
R2p	Rubber intercrop (Poorly managed)	0.08	Present use can be continued. Suitable for residential purposes

Table 21: *Proposed land use changes in highly suitable areas for residential purposes*

Land use in the built-up areas of protected areas can continue as long as those areas are continually protected, and with the approval of the relevant authorities. Lands could be developed according to urban plans. Home garden use should seek to minimize further encroachment, but settlements in the area can continue with the approval of the relevant authorities. Playgrounds are additional areas that should either be protected, or relocated to suitable land, with the abandoned land becoming protected.

Most agricultural land use can continue under a typical business-as-usual model, with present use being monitored to maximize crop cover and minimize ecological impact, however; there are a few notable exceptions to proposed changes in protected areas. Rubber intercrop and mono crop areas should be scaled back, and additional areas converted to protected areas. Poorly-managed coconut and cinnamon, as well as moderately managed bananas should have additional areas placed under protection. Market gardens fit into this consideration as well. All forms of paddy agriculture seem sufficiently well-managed, with ecological damage minimized. All forest land use types, scrub, water bodies (including marshes) are currently well-managed, and can continue under present protection paradigms.

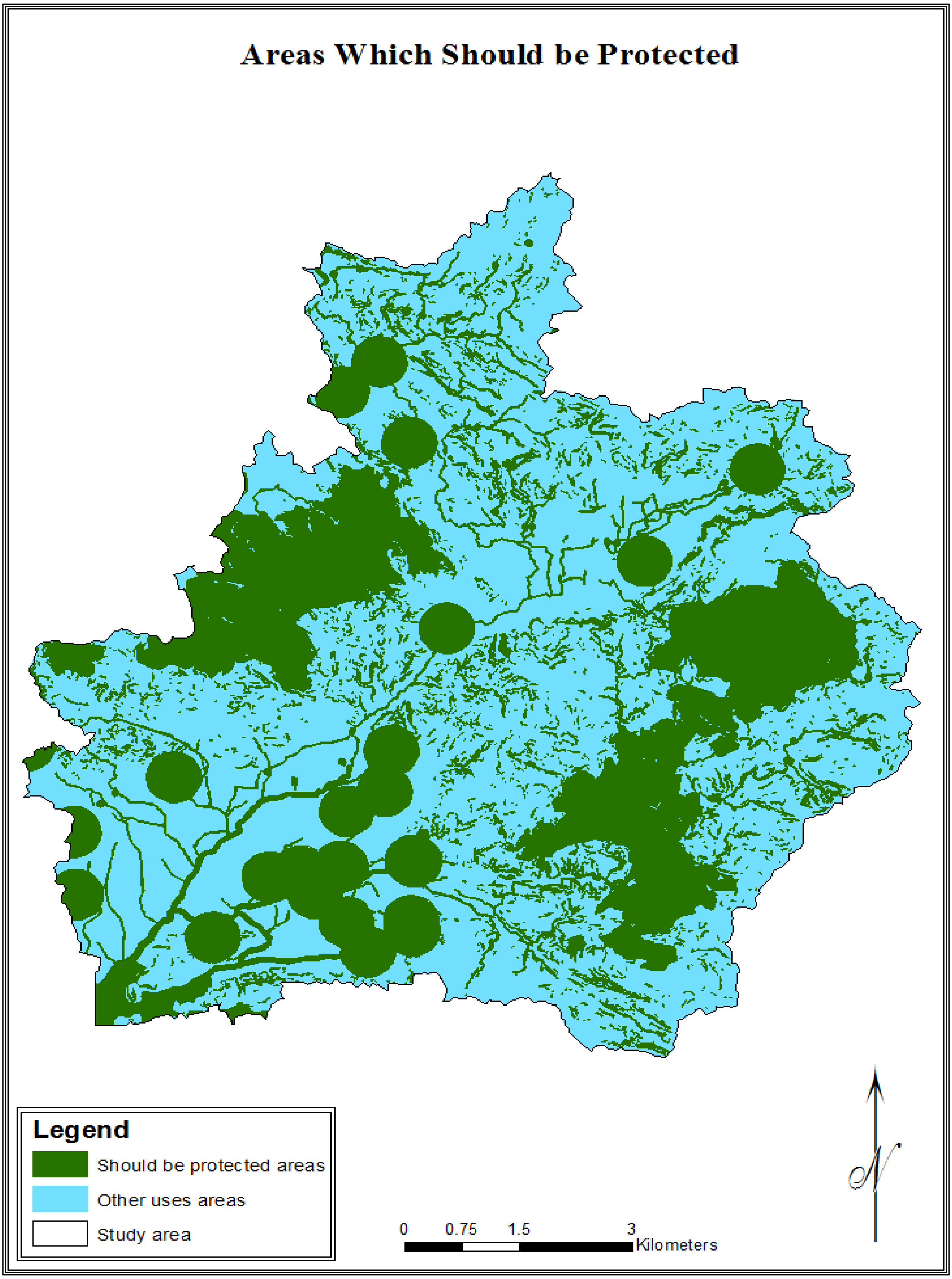

Figure 15: Areas which should be protected.

CONCLUSION

Considering land use changes analysis can assist in identifying the spreading of built-up areas. Most of the land uses were converted in to built-up areas. Suitability analysis is very important for creating a land use plan. To propose a land use plan, understanding current land uses is crucial; some lands are established as permanent, e.g., residential and built up areas. Here, the introduction of new land uses for those land uses was not undertaken, however; this could be the focus of future research in this area. This area is highly developed and natural resources are overused; complicating the study. Further, delineation of sub-water sheds is very difficult, even when utilizing the power of a GIS. To prepare a proposed land use plan, data on present land use is the most vital. The research has identified which areas should be protected from human activities and what are the suitable areas for different land use activities for future land use reservations. Hence, these areas need to be completely protected. Currently we can identify many human activities in these areas such as unsuitable construction, improper land managements for different purposes, and infiltration to natural resources due to political power and wealth. Land use analysis can propose which areas should be changed and what areas should remain in their current land use configuration based on the available technological knowledge. Furthermore, the research has found the most suitable areas to develop for future land use purposes such as land reservations, most suitable areas for agricultural activities, and residential purposes and the industrial purposes. Further research may track changes over these areas, and continue to examine them for changes which may be detrimental to the overall ecological health of the region.

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