Journal of Geographic Information System, 2015, 7, 177-190
Published Online April 2015 in SciRes. http://www.scirp.org/journal/jgis
http://dx.doi.org/10.4236/jgis.2015.72015

Analysis of Watershed Attributes for Water Resources Management Using GIS: The Case of Chelekot Micro-Watershed, Tigray, Ethiopia

Tesfaye Gebre[1], Tigist Kibru[1], Samuale Tesfaye[1], Gebeyehu Taye[1,2]

[1]Department of Land Resources Management and Environmental Protection, Mekelle University, Mekelle, Ethiopia
[2]Department of Earth and Environmental Sciences, KU Leuven, Belgium
Email: tesfaye.gebre60@gmail.com

Received 27 January 2015; accepted 11 April 2015; published 15 April 2015

Abstract

This study identified the importance of watershed attributes for water resource management using ArcGIS software, ASTER DEM and satellite images for the Chelekot micro-watershed, Tigray, Ethiopia. The study also evaluate the different hydrological parameters which are significant for the water resource management within the micro-watershed and finds the alternative solutions for water harvesting in the study area through the introduction of suitable soil and water conservation structures based on the finding. Principal watershed attributes including drainage pattern, topographic parameters, land use types, and soil types were evaluated and interpreted for the study micro-watershed. ArcGIS software was used for the computation, delineation of the boundary and morphometric analysis of the micro-watershed using topographical maps and ASTER DEM data. Results indicate that the micro-watershed has classified as a dendritic pattern with stream orders ranging from first to fifth order. The micro-watershed has homogeneity in texture and lack of structural control of surface flow. The drainage density is medium which indicates the area contains soils with medium infiltration rates and moderate relief. Drainage texture, stream frequency and the form factor of the micro-watershed are 4.1, 1.7 and 0.4 respectively. The bifurcation ratio of the micro-watershed ranges from 1 to 4.5 and the elongation ratio is 0.7 which reveals that the micro-watershed belongs to the less elongated shaped micro-watershed category. The mean bifurcation ratio of the whole micro-watershed is 3.3 indicating that the drainage pattern is not greatly influenced by geological structures. The micro-watershed land covers includes: cultivated land (75.8%), settlement and open land (10.5%), shrubs and plantation (13.2%), and water body (0.4%). The major soil types are Vertisol (58%), Camisole (32%), Regosol (9.5%) and Luvisol (0.7%). The textural classes are clay (5%), silty clay (22%), clay loam (17%), sandy loam

How to cite this paper: Gebre, T., Kibru, T., Tesfaye, S. and Taye, G. (2015) Analysis of Watershed Attributes for Water Resources Management Using GIS: The Case of Chelekot Micro-Watershed, Tigray, Ethiopia. *Journal of Geographic Information System*, **7**, 177-190. http://dx.doi.org/10.4236/jgis.2015.72015

(21%) and loam (35%) based on the soil textural map of the micro-watershed. Our results revealed that using GIS and ASTER DEM data based watershed morphometric analysis and hydrological evaluation at watershed scale is more applied and precise compared to other available *techniques*.

Keywords

GIS, Morphometric Analysis, Watershed, Drainage Frequency, Drainage Density, Chelekot, Ethiopia

1. Introduction

In semi-arid and arid areas of Africa, urban expansion, irrigation projects, and climate change, along with insufficient and unpredictable pattern of the rainfall pose pressure on existing water resources. Surface and ground water resources are inadequate to meet the crop water requirement and water for domestic consumption due to a rapid population growth and the demand for more water. The demand for water has increased over the years making the assessment of the quantity and the quality of water resources and its optimal utilization most critical. There is an urgent need for the evaluation of water resources as water plays a primary role in the sustainability of livelihoods and regional economy. Water management is the primary safeguard against drought and plays a central role in achieving food security at the local, national and global levels. Ever-growing population and urbanization are leading to over-utilization of water resources, thus exerting pressure on the limited civic amenities many of which are on the brink of collapse [1] [2].

Identification of ground features such as geological structures, geomorphic features and their link to hydrological characteristics may serve as direct or indirect indicators of ground and surface water potential of an area. The geomorphic conditions are essential prerequisites in understanding the water bearing characteristics of hard rocks and drainages patterns. The function of rocks types and geologic structures in the development of stream networks can be better understood by studying the nature and type of drainage patterns and by a quantitative morphometric analysis. The watershed's morphometric parameters are reflective of its hydrological response to a considerable extent and can be helpful in synthesizing its hydrological behaviour and water balance. A quantitative morphometric characterization and analysis of a watershed is considered to be the most satisfactory method for proper watershed management planning and implementation of soil and water conservation measures. The characterization of geomorphic attribute enables us to understand the relationship among different aspects of the basin's drainage pattern and also enables a comparative evaluation of different drainage basins developed in various geologic and climatic regimes [3].

Remote sensing data, along with increased resolution from satellite imagery, makes these technologies appear poised to make a large impact on land resource management initiatives involved in monitoring of land use and land cove (LULC) mapping and change detection. These tools are enabling researcher to determine varying spatial ranges in semi-arid regions which are undergoing severe moisture stresses due to the combined effects of rainfall variability, climate change and growing population [4].

Surface hydrological indications are promising scientific tools for assessment and management of water resources. Drainage morphometric analyses are a prerequisite for selection of water recharge sites, watershed modeling, runoff modeling, watershed delineation, groundwater prospect mapping and geotechnical investigation [5] [6]. The drainage network analysis is generally performed using the prevailing geological variation, topographic information and structural set of a basin and their interrelationships. Remote sensing and GIS based drainage basin evaluation has been conducted by various researchers for different terrains. This analysis is confirmed to be a very scientific tool for generation of precise and updated information for characterization of drainage basin parameters [7]-[11].

Digital elevation models (DEMs), such as from the ASTER, GDEM and other types of models were used to extract diverse geomorphological parameters of drainage basins, including drainage networks, catchment divides, slope gradient and aspect, and upstream flow contributing areas [12] [13]. GIS based watershed evaluation using Shuttle Radar Topographic Mission (SRTM) data have given a precise, fast, and an inexpensive way for analyzing hydrological systems [14] [15].

The study was conducted in warm temperate and sub-humid area of Tigray regional state [16]. The area received maximum recharge through rainfall and required integrated watershed management based morphometric analysis, to recognize the overall status of the watershed. The hydrological analysis and morphometric evaluation of Chelekot micro-watershed were conducted for water resource development and management through the use of GIS software, DEM, and satellite images analysis. The study aimed to explore the different watershed terrain and morphometric parameters and to understand the potential of the Chelekot micro-watershed for sustainable water resource management.

2. Materials and Methods

2.1. Study Area

The study was conducted in Enderta woreda, South-East zone of Tigray Regional State, which lies between 13˚ - 14˚N latitude and 39˚ - 40˚30" East longitudes. Enderta woreda consists of two main towns such as Mekelle and Kwiha. In addition there are several small towns including: Aynalem, May Keyah, May Mekden, and Aragure. Prominent villages in this district are: Chelekot, Debri, Kokolo, Adi Negoda and Alem. The study was carried out in Chelekot micro-watershed, where the lift irrigation project was proposed. This study site was selected to investigate the various characteristics of the micro-watershed and to understand the water resource potential of the area. In addition, the main aim of the project was to improve the livelihood of the farmers by introducing irrigation projects.

The Chelekot valley is located about 16 km west of Mekelle town. The valley is faulted and the rock beds are disturbed with a lithological composition of shale, marl dolerite intercalation and alluvium sediments. The mean annual temperature of this area ranges between 16˚C - 20˚C. The average annual rainfall of the area ranges between 500 - 1000 mm. This area is characterized by erratic rainfall and frequent droughts. The rainy season is occurring between June and September and the subsistence agricultural production is almost entirely dependent on this timing of the rainfall [16].

The study area consists of different types of lithology which varies with the morphology. Morphologically, the study area is divided into three major land systems: the Mekelle “Plateau”, the Ethiopian Rift Escarpment and the Giba River Tributaries. In general, the most common soils of the study woreda (Enderta) are: Calcisols, Cambisols, Kastanozems, Leptosols, Luvisols, Phaozems, Regosols, Vertisols and Fluvisols. The Fluvisols are mainly confined to the alluvial deposits along the river valley [16]. The natural vegetation cover is made up of *Cactus* (*Opuntia ficus indica*), grasses and scrubs with short trees. This area was once been densely forested with species such as *Juniper procera* and *Olea africana* [17] [18]. The natural forest was severely deforested. The remnant of this forest could be seen in churches, reserved areas and on the Ethiopian Rift Escarpment. Currently, the study area has low forest productivity due to the dry climate, poor soils, and topographic constrains [18]. Historic forest lands have been converted into farm and grazing lands over the centuries, except for patchy remnants of old-aged Afromontane forests around most Ethiopian Orthodox Tewahido Churches [19]. Fortunately, the vegetation is now being rehabilitated by the implementation of exclosures (areas protected from human and livestock interference) policies. The most representative plant species in the exclosures are: *Acacia etbaica* and *Tarchonanthus camphoratus*. Most of the previously deforested areas are now being re-afforested with exotic plant species such as *Eucalyptus globulus* and *Eucalyptus camaldulensis*. These trees are the main species used for construction purpose in the woreda.

2.2. Data Sources and Analysis

In this study an integrated use of multispectral satellite data, the digital elevation model (DEM) and Ethiopia topographical sheets were utilized for database generation and extraction of various drainage parameters. The details of data type, software and sources used are discussed below:

The micro-watershed area was delineated from rectified; mosaiced Ethiopian Mapping Authority (EMA) topographic maps at 1:50,000 scale printed by the EMA [20], with Transverse Mercator Projection (grid: UTM zone 37N), Clarke 1880 as spheroid and Adindan datum. These topographic maps were drawn using panchromatic aerial photo acquired by Swedsurvey on January 1994, and some field completion by EMA on March 1996. The topographic maps were scanned into digital format, georeferenced and utilized as reference images to operate geometric corrections on other remote sensing data. The maps were also used during field surveys; digitization of the drainage network, and catchment boundary. Drainage network was digitized and the number and lengths of streams of each order; watershed area; watershed perimeter; and total watershed length, and width were calculated using ArcGIS 9.3 software. Drainage density, drainage frequency, bifurcation ratio, form factor, circulatory ratio, and elongation ratio were calculated using methods suggested by various researchers for morphometric analysis. The summery of formulae (the methodologies) applied for the computation of morphometric parameters are given in **Table 1**. In addition, all geocoded toposheets were formed into mosaic using ERDAS Imagine 9.1 image processing software. The Chelekot micro-watershed area was delineated from ASTER DEM and Survey of Ethiopian topographical sheets by using the data preparation option of ERDAS Imagine Software. This was accomplished by making the watershed an Area of Interest (AOI). The same AOI was used to cut the study area satellite Image.

The soil type and texture analysis was carried out at Mekelle University Soil Laboratory, Mekelle. The USDA particle size classes, viz. Sand (2.0 - 0.05 mm), Silt (0.05 - 0.002 mm) and Clay (<0.002 mm), were followed when assigning textural classes. The soil texture was analysed by using hydrometric method [21].

2.3. Satellite Images

To obtain the land unit map and update the basin's drainage map of the micro-watershed, a set of 4 Landsat-7 ETM and 2 Landsat-5 TM images (Landsat ETH+ data of the year 2005) which is already orthorectified, were downloaded from Global Land Cover Facility (GLCF). Two sets of Landsat-7 images (acquired on 27 January,

Table 1. Formulas adopted for calculations of morphometric parameters.

Parameters	Formulae	References
Stream order (U)	Hierarchical rank of streams	[22]
Stream length (L_u)	Length of the stream	[23]
Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ where: L_{sm} = mean stream length, L_u = total stream length of order "U", N_u = total no. of stream segments of order "U"	[22]
Stream length ratio (R_L)	$R_L = L_u/(L_u - 1)$ where, R_L = stream length ratio, L_u = the total stream length of the order "U", $L_u - 1$ = the total stream length of its next lower order	[23]
Bifurcation ratio (R_b)	$R_b = N_u/N_u + 1$ where, R_b = bifurcation ratio, N_u = total number of stream segments of order "U", $N_u + 1$ = number of segments of the next higher order	[24]
Mean bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratios of all order	[25]
Stream frequency (F_s)	$F_s = N_u/A$ where, F_s = stream frequency, N_u = total no. of streams of all orders, A = area of basin	[23]
Drainage texture (T)	$T = D_d \times F_s$ where, T = Drainage texture, D_d = drainage density, F_s = stream frequency	[26]
Drainage density (D_d)	$D_d = L_u/A$ where, D_d = drainage density, L_u = total stream length of all orders, A = area of basin	[23]
Circularity ratio (R_c)	$R_c = 4\pi A/P^2$ where, R_c = circularity ratio, pi = pi value, A = area of basin, P^2 = square of the perimeter	[22]
Elongation ratio (R_e)	$R_e = \frac{2\sqrt{A/\pi}}{L_b}$ where, R_c = circularity ratio, A = area of basin pi = pi value, L_b = basin length	[25]
Form factor (F_f)	$F_f = A/L^2$ where, F_f = form factor, A = area of basin (km), L_b^2 = square of the basin length	[23]
Relief	$R = H - h$ where, R = relief, H = Vertical distance of the lowest highest points = Vertical distance of the lowest points of watershed in (m)	[27]
Relief ratio	$R_h = H/L_b$ where, R_h = relief ratio, H = total relief of the basin in km, L_b = basin length	[28]
Length of overland flow (Lg)	$Lg = 1\ D_d \times 2$ where, Lg = length of overland flow, D_d = drainage density	[23]

2000 and 05 February, 2000) were merged in a mosaic. ASTER DEM, with a 15 meters spatial resolution, were also purchased, but needed to be orthorectified and georeferenced. Google Earth images were a complementary tool during the photo-interpretation because of their high resolution of most of the study area. This allowed a good determination of the land use and land cover pattern of the micro-watershed. This collection of different satellite images and photos was also useful for multi-temporal analysis. DEM of the micro-watershed was extracted from ASTER data obtained during February 2005 with resolution of 90 m, downloaded from the GLCF. The ASTER DEM was utilized to prepare topographic, slope and delineation of drainage map of the micro-watershed using the ArcGIS 9.3 spatial analyst tool. The field data and topographic maps were analyzed using geographic information system (ArcGIS) and ERDAS imagine softwares. In addition, different techniques were used for conducting LULC mapping such as image restoration, enhancement and classification of the satellite imageries.

3. Results and Discussion

3.1. Linear Aspects

The basin area, basin perimeter, and basin length of the Chelekot micro-watershed were found to be 106 km^2, 44 km, and 16 km respectively. Streams are classified based upon their form and patterns or networks they create in the landscape. The term “stream network” refers to the connectivity of the stream tributaries and is becoming an increasingly important concept because it is used in GIS hydrologic distributed modeling [29]. The results of the study indicate that the pattern classification of the micro-watershed is a dendritic type, which is characterized by homogenous subsurface strata. The order wise stream numbers and their linear characteristics are shown in **Table 2**. The micro-watershed drainage pattern analysis indicated that the area has few structural or tectonic controls. The stream order of the micro-watershed varies from first orders to fifth orders. Large number of stream was found in the first and second orders. As the stream order increases the total number of streams decreases. The drainage map with stream order of the Chelekot micro-watershed is shown in **Figure 1**. Stream ordering of the micro-watershed was computed using ArcGIS 9.3 software by applying the methods proposed by [23]. The total length of stream segment is highest in first order streams and decreases as the stream order increases. This change in stream orders may indicate flowing of streams from high altitude and the physical characteristics of rock variations. The total length of streams in the micro-watershed is about 177.1 km. The mean stream length (L_{sm}) and their ratio have been also computed using GIS software (**Table 2**). The understanding of streams in a drainage system constitutes the drainage pattern, which in turn replicates mainly structural or lithologic controls of the underlying rocks. The micro-watershed has a classification of dendritic drainage patterns, despite stream lengths and other hydrological properties. They are generally characterized by a treelike branching system or dendritic arrangements of small streams or tributaries in the headwaters (branches) that flow in a variety of directions, continually joining larger streams, eventually forming a “major” stream or river.

The total length of stream segments decreases as the stream order increases (**Figure 1**). The connection between the bifurcation ratio and the stream length ratio is determined by hydrogeologic, physiographic and geological characteristics. The values of total length, mean length and length ratio of the diverse stream orders of the micro-watershed are shown in **Table 2**. Stream length and their ratio are very important parameters to scan

Table 2. The linear parameters of the Chelekot micro-watershed.

No.	Parameters	Stream order (W)					Total
		I	II	III	IV	V	
1	Number of stream (N_u)	130	38	9	2	1	180
2	Bifurcation ratio (R_b)		3.42	4.22	4.5	1	
3	Mean bifurcation ratio (R_{bm})	3.29					
4	Total length of streams (km)	97.32	45.53	19.89	5.71	8.63	177.08
5	Mean length of streams (km)	0.98					
6	Stream length ratio (R_L)	3.71					

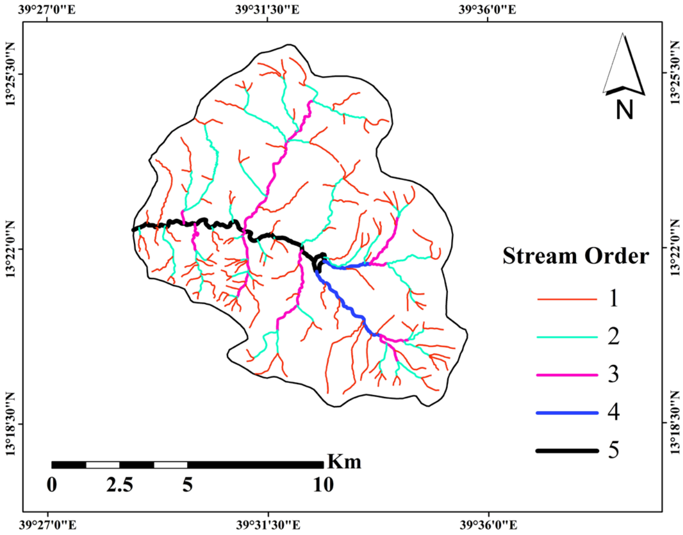

Figure 1. Drainage map with stream orders of the Chelekot micro-watershed.

the hydrological characteristics of the river basin because they characterize the permeability of the rock formations in a basin. It also indicates if there is a major change in the hydrological characteristics of the underlying rock surfaces within the basin [2].

The results showed that the bifurcation ratio (R_b) values ranging between 1 and 4.5 and the mean bifurcation ratio of the micro-watershed is 3.3. This indicates that the drainage pattern has not been affected by structural disturbances and the observed R_b is not the same throughout stream orders of the micro-watershed. These irregularities depend upon the watershed geological and lithological development (**Table 2**). Bifurcation ratio values of the micro-watershed ranging between 3 and 4.5 characterize a basin which has experienced minimum structural disturbances [22]. The higher value of R_b indicated strong structural control on the drainage pattern and also streams that have a higher average flood potential due to numerous tributary segments drain into relatively few trunk transporting stream segments. This shows its usefulness for hydrograph shape for watersheds similar in other respect. An elongated watershed has higher bifurcation ratio than normal and approximately circular watershed [2] [30] [31].

3.2. Areal Aspects

The results of this study indicated that the drainage density of the Chelekot micro-watershed is 1.7. Lower drainage density of the micro-watershed indicates towards coarse drainage pattern and sub-humid climate of the study area. The coarse texture gives more time for the infiltration of overland flow and hence to groundwater recharge. A low value of the drainage density indicates a relatively low density of streams and thus a slow stream response to runoff [32] [33]. Drainage density has classified into five different textures. A drainage density less than 2 indicates “very coarse”, between 2 and 4 is “coarse”, between 4 and 6 is “moderate”, between 6 and 8 is “fine” and greater than 8 is “very fine” drainage texture [26]. The micro-watershed has a drainage texture of 4.1which indicates the moderate drainage texture. Similarly, the moderate drainage texture and medium value of drainage density indicates the presence of moderately resistant semi-permeable material with moderate relief. The variation of the values of drainage texture depends upon a number of natural factors such as climate, vegetation, rock type, soil type and their infiltration capacity and relief of the micro-watershed. Medium drainage density results from moderate or semi-permeable subsurface material, medium vegetation cover and moderate relief results moderate infiltration capacity. High drainage density results from weak or impermeable subsurface material, thin vegetation and mountainous relief [2]. The stream frequency of the micro-watershed is 1.7. The stream frequency value indicates a positive correlation with the micro-watershed drainage density suggesting that an increase in stream population occurs with respect to increase in drainage density. The low stream frequencies value indicates sparse drainage network favouring groundwater recharge. The calculated elongation ratio of the micro-watershed is 0.7, which suggests that the basin belongs to the less elongated shape basin and moderate relief. The values of elongation ratio (R_e) generally vary from 0.6 to 1.0 over a wide variety of climatic, topography and geologic conditions [10]. The values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are usually associated with high relief and steep surface slope. These values can be grouped into three categories: 1) circular (>0.9); 2) oval (0.9 to 0.8); 3) elongated (<0.7) [22]. The circularity ratio of the micro-watershed is 0.68. Circularity ratios range 0.4 to 0.5 which indicates strongly elongated and extremely permeable homogenous geologic materials. The result of circularity ratio of the micro-watershed indicates that the basin is less elongated in shape, has moderate runoff discharge and semi-permeable subsoil circumstances. It is influenced by the frequency and length of streams, geological structures, land use/land cover, climate, relief and slope of the micro-watershed [34]. The calculated form factor value of the micro-watershed is 0.4 suggesting that the shape of the basin is elongated. The elongated micro-watershed with low form factor indicates that the basin will have a flatter peak of flow for longer duration and conducive for more groundwater recharge. The form factor indicates the flow intensity of a basin for a defined area. Watersheds with high form factors experience larger peak flows of shorter duration, indicating less contact time and less infiltration whereas elongated watershed with low form factors experience lower peak flows of longer duration. A perfectly circular watershed have form factor value of >0.78 [35]. The shorter length of overland flow the quicker surface runoff will enter the stream. In the present study the length of overland flow is 0.30. The value indicates that there is less structural disturbance, less runoff conditions and having moderate overland flow. A larger value of length of overland flow indicates longer flow path and thus, gentler slopes. The length of overland flow is the most important variables affecting terrain development of drainage basin. The length of overland flow is mostly influenced by both hydrologic and physiographic structures of the area. The overland flow is related inversely to the average slope of streams and it is directly equal to the reciprocal of drainage density [23] [36].

3.3. Relief Aspects

In the present study, the relief ratio (R_h) value of the micro-watershed is 25.2 which shows that the major portion of the micro-watershed is having moderately steep slopes (**Table 3**). It measures the overall steepness of the micro-watershed and is an indicator of the intensity of the soil erosion processes operation on the watershed's slope. The high value of relief ratio is characteristics of hilly areas with high runoff production and soil erosion.

3.4. Aspect and Slope Map of the Micro-Watershed

The aspect map is a very important parameter for understanding the impact of sun on the area's local climate. In most cases a west-facing slope will be warmer than an east-facing slope, especially in the afternoon. Aspect has major effects on vegetation distribution. The aspect map of the Chelekot micro-watershed was derived from ASTER DEM and represents the compass direction of the aspect. 0_ is true north; a 90_ aspect is to the east (**Figure 2**). The result indicates the Chelekot micro-watershed shows a high percentage of east-facing slopes. These slopes have relatively higher soil moisture content and moderate vegetation compared to west facing slope of the micro-watershed.

The highest elevation in the micro-watershed is 2424 m a.s.l. and the lowest is 2019 m a.s.l. exists in the western and northwestern parts of the micro-watershed which induces highest runoff and thus, less possibility for rainfall water infiltration. The slope map of the study micro-watershed is grouped in to six classes in percents. 0% - 3% (flat or almost flat), 3% - 8% (gentle slopping), 8% - 15% (sloping), 15% - 30% (moderately steep), 30% - 50% (steep) and >50% (very steep) (**Figure 3**). Most of the area of Chelekot micro-watershed is classified as moderately steep slope. Gentle slopes were designated in the "excellent" category for groundwater management as the nearly flat terrain is favorable for more infiltration. Moderate slopes are also considered "good" due to slightly undulating topography which gives maximum percolation or partial runoff. The "steep" class areas, having a high surface runoff with least amount of soil infiltration are regarded as good locations for construction

Table 3. Relief characteristics of the Chelekot micro-watershed.

Height of basin mouth (z) m	Maximum height of the basin (Z) m	Total basin relief (H) m	Relief ratio
2019	2424	405	25.15

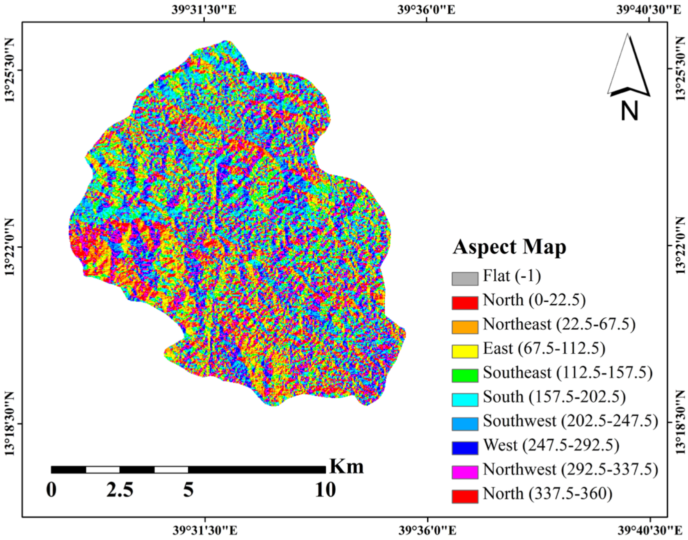

Figure 2. Aspect map of the Chelekot micro-watershed.

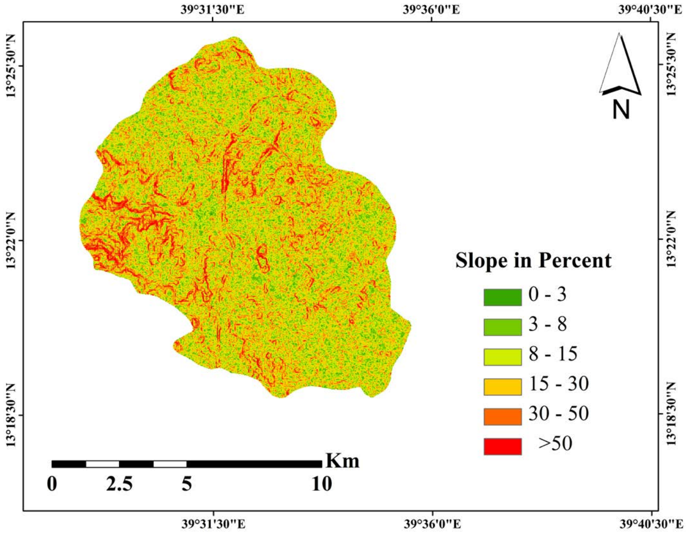

Figure 3. Slope map of the Chelekot micro-watershed indicating the range of slope gradients in percent.

of stop dams for water harvesting or infiltration ponds to recharge the groundwater. Slope is a crucial parameter which directly controls the balance between runoff response and soil infiltration rates of a terrain. High runoff production in higher slope regions results in less soil infiltration. This factor significantly controls the development of aquifers.

3.5. Land Use/Land Cover Mapping

Figure 4 indicates the land use land cover map of the micro-watershed which constitutes water body (0.4%), shrub and plantation area (13.2%), settlement and opens land (10.5%) and cultivated land (75.8%). The larger portion of the micro-watershed is covered by cultivated land. Land use land cover pattern changes are important factors for assessing water resource conditions. Water resources are under severe pressure due to land use practices with high water requirements and climate change. Land use pattern changes and their estimation describe the utilization of land resource by manmade activities, particularly agriculture and urbanization [4] [37] [38]. Hydrological inferences from land use patterns can help to understand the changing scenario of water demand

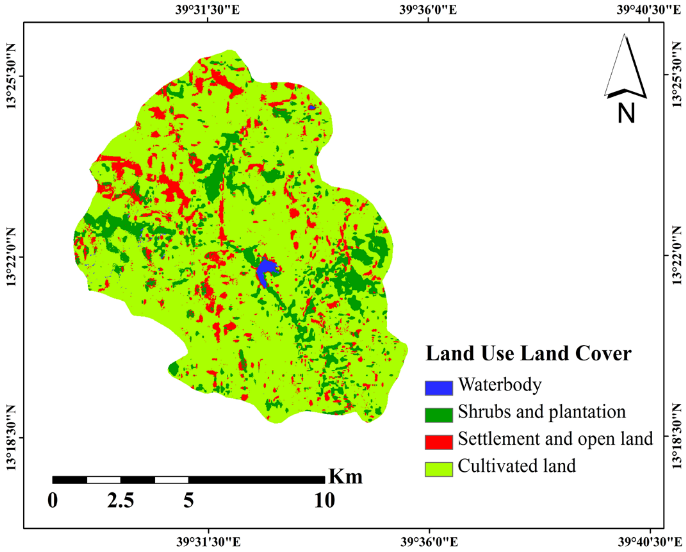

Figure 4. Land use land cover map of the Chelekot mi cro-watershed.

from different activities such as agricultural use, domestic needs and industrialization. It can also used to understand rain water infiltration in the micro-watershed, recharge to the groundwater and surface runoff rates. Land use pattern changes become an important component in hydrological monitoring, modeling and natural resources management in general [39] [40]. An analysis of land use changes for hydrologic processes is a major need for the future [41]. This includes: changes in water demands from changing land use practices such as introduction of irrigated agriculture and urbanization and changes in water supply from altered hydrological processes of infiltration, groundwater recharge and surface runoff. Many researchers reported that land use maps are very important inputs for understanding and managing watershed hydrological conditions [2] [42]. Assessment of land use land cover pattern of the micro-watershed reveals that most of the area is cultivated land, which indirectly supports the future for watershed development and management (**Table 4**).

3.6. Soil Type Classification

The results indicated that the soil types of the micro-watershed were Pellic Vertisol, Vertic Cambisol, Profoundic Luvisol, Calcaric Regosol, and Haplic Cambisol (**Figure 5**). The Pellic Vertisol (58%), Vertic Cambisol (32%), Calcaric Regosol covering (9.5%), Profoundic Luvisol (0.7%) and Haplic Cambisol which covers about 0.1% of the area (**Table 5**). The largest proportion of the micro-watershed is covered by Pellic Vertisol and Vertic Cambisol soil types. In the eastern part of the region the soils are mostly developed under arid conditions where the weathering process is slow and as a result very shallow soils are developed. Cambisols and Vertisols are developed in the higher rainfall areas of the south on alluvium derived from basalt [16].

The majority of the soils of this region are reported to be shallow with low soil fertility, high runoff, and low infiltration capacity [43]. Declining soil fertility is particularly severe in Tigray because of high nutrient losses through soil erosion and extremely low fertilizer and manure inputs [44].

3.7. Soil Texture of the Micro-Watershed

The soil texture was the only physical property that received laboratory analysis. Texture influences the porosity and the degree of soil compaction, which in turn, influences the movement and availability of water in the soil. Sandy soils contain mostly large pores. They hold little water, and excess water drains through them easily. A loam is a soil that contains a roughly balanced mixture of sand, silt, and clay. Soils which are mostly silt or clay have mostly small pores that do not drain water readily. Loamy soils have more chemical activity than sandy soils, and hold more water [45]. They offer more protection to groundwater management. Also, water tends to infiltrate through them more readily than through fine-textured soils, so the risk of runoff is less. The predominant textures of the soil profiles in the entire study micro-watershed were found to be: clay (5%), silty clay

Table 4. Land use land cover of the Chelekot micro-watershed.

Land Use Type	Area (Sq.m)	Area (Sq.km)	Percentage (%)
Water body	464565.6	0.5	0.4
Shrubs and plantation	14056567.2	14.1	13.2
Settlement and open land	11153642.4	11.2	10.5
Cultivated land	80663151.6	80.7	75.8
Total	106350130.8	106.3	100

Table 5. Soil type and its area coverage of the Chelekot micro-watershed.

Soil type	Area (Sq.m)	Area (Sq.km)	Percentage (%)
Vertic Cambisol	33807163.3	33.8	31.8
Haplic Cambisol	77297.5	0.1	0.1
Pellic Vertisol	61461421.0	61.5	57.9
Profoundic Luvisol	774780.5	0.8	0.7
Calcaric Regosol	10066943.2	10.2	9.5
Total	106187605.4	106.3	100.0

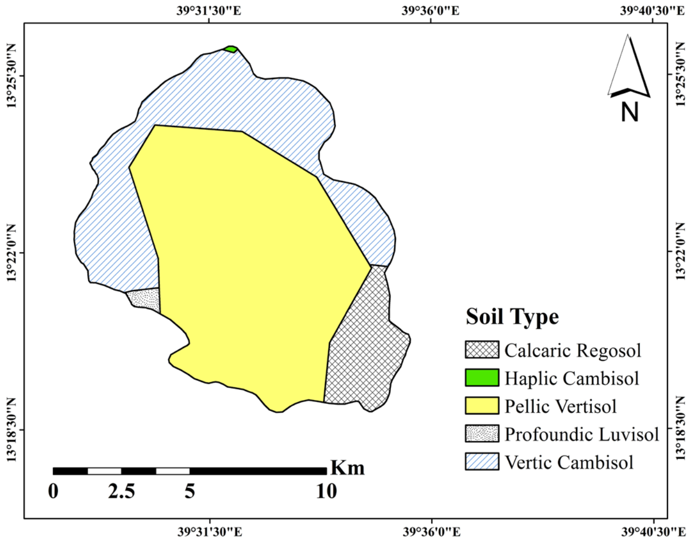

Figure 5. Soil type map of the Chelekot micro-watershed.

(22%), clay loam (17%), sandy loam (21%) and loam (35%) (**Table 6**; **Figure 6**). According to [46], soil erosion depends much on the infiltration rate of a soil. The infiltration rate is depending on the soil texture. In a sandy soil the infiltration rate is higher than in a silty soil. In a clayey soil it may be initially high (for heavy black clay with cracking), but becomes low when the soil is moist to wet.

3.8. Effects of Morphometric Analysis in the Hydrological Processes

Application of GIS and DEM for analysis of a micro-watershed's morphological attributes plays a significant role for proper hydrological study of any terrain which indirectly maintains the hydrogeological condition of the watershed. The quantitative analysis of watershed attributes is found to be of great utility in watershed delineation, soil and water conservation and watershed management. The analysis of watershed attributes conducted in

Table 6. Soil texture class of the Chelekot micro-watershed area in percent.

Soil texture class	Area (Sq.m)	Area (Sq.km)	Percentage (%)
Clay	5578980.6	5.6	5.2
Silty clay	23672742.0	23.7	22.3
Clay loam	18296053.7	18.3	17.2
Sandy loam	21851973.3	21.9	20.5
Loam	36988445.5	37.0	34.8
Total	106388195.1	106.3	100.0

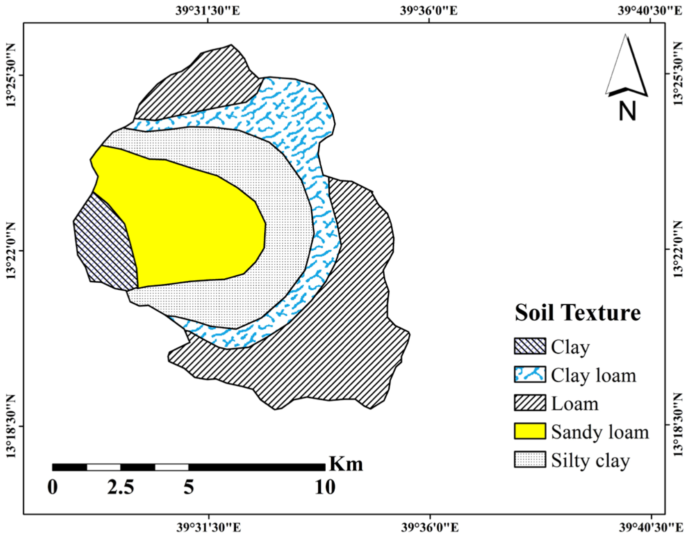

Figure 6. Soil texture map of the Chelekot micro-watershed.

the Chelekot micro-watershed confirmed that the watershed has moderate relief and less elongated shape. Artificial recharge and runoff harvesting for groundwater development are selected based on small-scale topographic maps. Drainage analysis makes a constructive input with the application of RS and GIS based tools in selecting artificial recharge sites in the area. These analyzed drainage parameters provide comparative indices of the permeability of rock surfaces. If this information is integrated with the other hydrological attributes, the strategy of sitting recharge and water harvesting measures provides better groundwater development and management plan for the area. The drainage pattern classification of the study micro-watershed is dendritic in nature. This may be due to more or less homogeneous lithology and structural controls. Moderate drainage density is observed over the hilly terrain with semi-permeable hard rock substratum, and moderate drainage density over the moderately semi-permeable sub-soils and moderate relief areas. Moderate drainage density areas are favorable for identification of groundwater potential areas. Slope of the micro-watershed plays a key role in determining infiltration and runoff production. Infiltration is inversely related to slope (*i.e.* the gentler the slope, the higher the infiltration) [2].

4. Conclusions and Recommendation

The results of analysis of the micro-watershed attributes show that the micro-watershed has a moderate relief and less elongated shape. The micro-watershed drainage network is dendritic type, indicating homogeneity in texture and requiring less structural controls. This type of basin structure helps explain various terrain parameters such as the nature of the bedrock, infiltration capacity, groundwater recharge, runoff production and soil erosion. A moderate drainage density and stream frequency indicate a moderate subsurface formation permeability rate. The observed parameters reveal recharge related measures, and areas where surface water augmentation measures can be undertaken for water resource management and soil conservation structures. A large scale watershed analysis using GIS, remote sensing data and Digital elevation Model (DEM), would be efficient for understanding terrain parameters such as the nature of bedrock, infiltration capacity, surface runoff. The resulting information would help in understanding the status of land form and their processes, drainage management, and groundwater potential for watershed planning and management. This study will be useful for water resource management at the micro level of any terrain, by planners and decision makers for sustainable watershed development programs.

The results of this study can be used for site suitability analysis of soil and water conservation structures. Subsequently, these parameters were integrated with other hydrological information, land use land cover, land forms, geology, water level and soil in the GIS domain to arrive at decisions regarding suitable sites for soil and water conservation structures (bund, check-dam, and percolation ponds, recharge shaft, etc.) for groundwater development and management. The study recommended that the micro-watershed needs detail and further hydrogeological and geophysical investigations for more proper water management and selection of artificial groundwater recharge structures.

Acknowledgements

We would like to thank Mekelle University and Tigray Bureau of Water Resources and Energy for providing financial support for undertaking the Watershed Feasibility study and Detail Design of Head Works of Chelekot irrigation schemes. We also appreciate Bob Sturtevant from Colorado State University, Amare Sisay from Hawassa University and Etefa Guyassa from University of Ghent, Belgium for their comments and suggestions.

References

[1] Jha, M.K, Chowdhury, A., Chowdary, V.M. and Peiffer, S. (2007) Groundwater Management and Development by Integrated RS and GIS: Prospects and Constraints. *Water Resource Management*, **21**, 427-467. http://dx.doi.org/10.1007/s11269-006-9024-4

[2] Singh, P., Thakur, J.K. and Singh, U.C. (2013) Morphometric Analysis of Morar River Basin, Madhya Pradesh, India, Using Remote Sensing and GIS Techniques. *Environmental Earth Sciences*, **68**, 1967-1977. http://dx.doi.org/10.1007/s12665-012-1884-8

[3] Sreedevi, P.D., Sreekanth, P.D., Khan, H.H. and Ahmed, S. (2013) Drainage Morphometry and Its Influence on Hydrology in a Semi-Arid Region: Using SRTM Data and GIS. *Environmental Earth Sciences*, **70**, 839-848. http://dx.doi.org/10.1007/s12665-012-2172-3

[4] Singh, P., Thakur, J.K. and Singh, U.C. (2011) Assessment of Land Use/Land Cover Using Geospatial Techniques in a Semi-arid Region of Madhya Pradesh, India. In: Thakur, J.K., Singh, S.K., Ramanathan, A., Prasad, M.B.K. and Gossel, W. (Eds.), *Geospatial Techniques for Managing Environmental Resources*, Springer and Capital Publication, Heidelberg, 152-163.

[5] Magesh, N.S., Chandrasekar, N. and Soundranayagam, J.P. (2011) Morphometric Evaluation of Papanasam and Manimuthar Watersheds, Parts of Western Ghats, Tirunelveli District, Tamil Nadu, India: A GIS Approach. *Environmental Earth Sciences*, **64**, 373-381. http://dx.doi.org/10.1007/s12665-010-0860-4

[6] Thomas, J., Joseph, S., Thrivikramji, K.P., Abe, G. and Kannan, N. (2012) Morphometrical Analysis of Two Tropical Mountain River Basins of Contrasting Environmental Settings, The Southern Western Ghats, India. *Environmental Earth Sciences*, **66**, 2353-2366. http://dx.doi.org/10.1007/s12665-011-1457-2

[7] Grohmann, C.H. (2004) Morphometric Analysis in Geographic Information Systems: Applications of free Software. *Computers & Geosciences*, **30**, 1055-1067. http://dx.doi.org/10.1016/j.cageo.2004.08.002

[8] Korkalainen, T.H.J., Lauren, A.M. and Kokkonen, T.S. (2007) A GIS Based Analysis of Catchment Properties within a Drumlin Field. *Boreal Environment Research*, **12**, 489-500.

[9] Hlaing, T.K., Haruyama, S. and Aye, M.M. (2008) Using GIS-Based Distributed Soil Loss Modeling and Morphometric Analysis to Prioritize Watershed for Soil Conservation in Bago River Basin of Lower Myanmar. *Frontiers of Earth Science in China*, **2**, 465-478. http://dx.doi.org/10.1007/s11707-008-0048-3

[10] Pankaj, A. and Kumar, P. (2009) GIS Based Morphometric Analysis of Five Major Sub-Watershed of Song River, Dehradun District, Uttarak-Hand with Special Reference to Landslide Incidences. *Journal of the Indian Society of Remote Sensing*, **37**, 157-166. http://dx.doi.org/10.1007/s12524-009-0007-9

[11] Javed, A., Khanday, M.Y. and Ahmed, R. (2009) Prioritization of Sub-Watersheds Based on Morphometric and Land Use Analysis Using Remote Sensing and GIS Techniques. *Journal of Indian Society of Remote Sensing*, **37**, 261-274.

http://dx.doi.org/10.1007/s12524-009-0016-8

[12] Mark, D.M. (1984) Automatic Detection of Drainage Networks from Digital Elevation Models. *Cartographica*, **21**, 168-178. http://dx.doi.org/10.3138/10LM-4435-6310-251R

[13] Tarboton, D.G. (1997) A New Method for the Determination of Flow Directions and Contributing Areas in Grid Digital Elevation Models. *Water Resources Research*, **33**, 309-319. http://dx.doi.org/10.1029/96WR03137

[14] Grohmann, C.H., Riccomini, C. and Alves, F.M. (2007) SRTM-Based Morphotectonic Analysis of the Poços de Caldas Alkaline Massif, Southeastern Brazil. *Computers & Geosciences*, **33**, 10-19. http://dx.doi.org/10.1016/j.cageo.2006.05.002

[15] Panhalkar, S.S. (2014) Hydrological Modeling Using SWAT Model and Geoinformatic Techniques. *The Egyptian Journal of Remote Sensing and Space Science*, **17**, 197-207. http://dx.doi.org/10.1016/j.ejrs.2014.03.001

[16] IAO (2008) Land Evaluation in Enderta District, Tigray, Ethiopia. Master's Thesis, università Degli Studi di Firenze, Firenze.

[17] TFAP (1996) Tigray Bureau of Agriculture and Natural Resources Development, Regional Government of Tigray, Mekelle, Ethiopia, 1-122. (Unpublished)

[18] Darbyshire, I., Lamb, H. and Umer, M. (2003) Forest Clearance and Regrowth in Northern Ethiopia during the Last 3000 Years. *The Holocene*, **13**, 537-546. http://dx.doi.org/10.1191/0959683603hl644rp

[19] Alemayehu, W.E. (2007) Ethiopian Church Forests: Opportunities and Challenges for Restoration. Ph.D. Thesis, Wageningen University, Wageningen.

[20] EMA (1997) Topographic Maps Edition 1, Based on: Field Survey Data by Ethiopian Mapping Authority EMA (1996), Air Photograph by Swedsurvey.

[21] Gee, G.W. and Bauder, J.W. (1986) Particle Size Analysis. In: Klute, A., Ed., *Methods of Soil Analysis. Part I—Physical and Mineralogical Methods*, Second Edition, American Society of Agronomy/Soil Science Society of America, 383-412.

[22] Strahler, A.N. (1964) Quantative Geomorphology of Drainage Basins and Channel Networks. In: Te Chow, V., Ed., *Hand Book of Applied Hydrology*, McGraw Hill Book Company, New York.

[23] Horton, R.E. (1945) Erosion Development of Streams and Their Drainage Basins: Hydrophysical Approach to Quantitative Morphology. *Bulletin of the Geological Society of America*, **56**, 275-370. http://dx.doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

[24] Schumm, S.A. (1956) Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey. *Bulletin of the Geological Society of America*, **67**, 597-646. http://dx.doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2

[25] Strahler, A.N. (1957) Quantitative Analysis of Watershed Geomorphology. *Transactions, American Geophysical Union*, **38**, 913-920. http://dx.doi.org/10.1029/TR038i006p00913

[26] Smith, K.G. (1950) Standards for Grading Texture of Erosional Topography. *American Journal of Science*, **248**, 655-668. http://dx.doi.org/10.2475/ajs.248.9.655

[27] Hadley, R.F. and Schumm, S.A. (1961) Sediment Sources and Drainage Basin Characteristics in Upper Cheyenne River Basin. US Geological Survey Water-Supply Paper 1531-B, 198.

[28] Schumm, S.A. (1963) Sinuosity of Alluvial Rivers in the Great Plains. *Bulletin of the Geological Society of America*, **74**, 1089-1100. http://dx.doi.org/10.1130/0016-7606(1963)74[1089:SOAROT]2.0.CO;2

[29] De Barry Paul, A. (2004) Watersheds: Processes, Assessment, and Management. John Wiley and Sons, Inc., Hoboken.

[30] Liaqat, A.K.R. and Alia, Y. (2013) Morphometric Analysis for Soil Erosion Assessment in Parts of Chambal Basin Using Remote Sensing and GIS, Madhya Pradesh. *International Journal of Advanced Technology & Engineering Research*, **3**, 134-141.

[31] Singh, R.K., Bhatt, C.M. and Prasad, V.H. (2003) Morphological Study of a Watershed Using Remote Sensing and GIS Techniques. *Hydrology Journal Indian Association of Hydrologists*, **26**, 55-66.

[32] Singh, A., Nestmann, K., Franz and Eldho, T.I. (2004) Estimating Hydrological Parameters for Anas Catchment from Watershed Characteristics. *Proceedings of the International Conference on Advanced Modeling Technique for Sustainable Management of Water Resources*, Warangal, 28-30 January 2004, 30-33.

[33] Pingale, S.M., Chandra, H., Sharma, H.C. and Sangita Mishra, S. (2012) Morphometric Analysis of Maun Watershed in Tehri-Garhwal District of Uttarakhand Using GIS. *International Journal of Geomatics & Geosciences*, **3**, 373-387.

[34] Miller, V.C. (1953) A Quantitative Geomorphic Study of Drainage Basin Characteristics on the Clinch Mountain Area, Virgina and Tennessee. Project NR 389-402, Technical Report Number 3, Columbia University, Department of Geology, ONR, New York.

[35] Sharkh, M.S.A. (2009) Estimation of Runoff for Small Watershed Using Watershed Modeling System (WMS) and GIS.

Proceedings of the Thirteenth International Water Technology Conference (*IWTC*), Hurghada, 12-15 March 2009.

[36] Kaliraj, S., Chandrasekar, N. and Magesh, N.S. (2014) Morphometric Analysis of the River Thamirabarani Sub-Basin in Kanyakumari District, South West Coast of Tamil Nadu, India, Using Remote Sensing and GIS. Environmental Earth Sciences. http://dx.doi.org/10.1007/s12665-014-3914-1

[37] Hartemink, A.E., Veldkamp, T. and Zhanguo, B. (2008) Land Covers Change and Soil Fertility Decline in Tropical Regions. *Turkish Journal of Agriculture and Forestry*, **32**, 195-213.

[38] Nian, Y.Y., Li, X., Zhou, J. and Hu, X.L. (2014) Impact of Land Use Change on Water Resource Allocation in the Middle Reaches of the Heihe River Basin in Northwestern China. *Journal of Arid Land*, **6**, 273-286. http://dx.doi.org/10.1007/s40333-013-0209-4

[39] Sylla, L., Xiong, D., Zhang, H.Y. and Bangoura, S.T. (2012) A GIS Technology and Method to Assess Environmental Problems from Land Use/Cover Changes: Conakry, Coyah and Dubreka Region Case Study. *The Egyptian Journal of Remote Sensing and Space Science*, **15**, 31-38.

[40] Rawat, J.S., Biswas, V. and Kumar, M. (2013) Changes in Land Use/Cover Using Geospatial Techniques: A Case Study of Ramnagar Town Area, District Nainital, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science*, **16**, 111-117.

[41] Turner, M.G., Pearson, S.M. and Bolstad, P. (2003) Effects of Land Cover Change on Spatial Pattern of Forest Communities in the Southern Appalachian Mountains (USA). *Landscape Ecology*, **18**, 449-464. http://dx.doi.org/10.1023/A:1026033116193

[42] Wagner, P.D., Kumar, S. and Schneider, K. (2013) An Assessment of Land Use Change Impacts on the Water Resources of the Mula and Mutha Rivers Catchment Upstream of Pune, India. *Hydrology and Earth System Sciences*, **17**, 2233-2246. http://dx.doi.org/10.5194/hess-17-2233-2013

[43] Mitiku, H. (1996) Soil Resources of Central Tigray: A Case Study of Selected Farms in 7 Woredas. In: Oyhus, A. and Gebru, G., Eds., *Rural Exploratory Studies in the Central Zone of Tigray*, *Northern Ethiopia*: *Proceeding of a Workshop*, Noragric, Addis Ababa, 19-33.

[44] Virgo, K.J. and Munro, R.N. (1978) Soil and Erosion Features of the Central Plateau Region of Tigray, Ethiopia. *Geoderma*, **20**, 131-157. http://dx.doi.org/10.1016/0016-7061(78)90040-X

[45] Wolf, B. (1999) The Fertile Triangle: The Interrelationship of Air, Water and Nutrients in Maximizing Soil Productivity. Food Products Press, New York.

[46] Daniel, D. (2001) Soil and Water Conservation Manual: Guideline for Ethiopia. Soil and Water Conservation Team, Natural Resources Management and Regulatory Department, Ministry of Agriculture, Addis Ababa.