The impact of topographical characteristics and land use change on the quality of Umbaniun micro-watershed water resources, Meghalaya

Impacto de las características topográficas y del cambio en el uso de la tierra en los recursos de la micro-cuenca Umbanium, Meghalaya

P.N. Rymbai[1], S.Dey[2], L.K. Jha[3]

ABSTRACT

A watershed is a geohydrological unit draining at a common point. Such natural unit has evolved through rain water interaction with land mass, typically comprising arable land, non-arable land and natural drainage lines in rain-fed areas. Sustainable production depends on the health, vitality and purity of a particular environment in which land and water are important constituents. A pilot study was thus undertaken to study the geomorphology, land-use systems and their impact on water resource management on the Meghalaya Umbaniun micro-watershed. In this Micro-watershed (3951.18 ha), water body covers an area of 5.69ha (0.14%). The paper highlights the linkage between geomorphology, land use systems and its impact on quality of water resources on the Umbaniun Micro-Watershed, Meghalaya. Topographical and physical-chemical characteristics, such as pH, conductivity, dissolved oxygen, turbidity and water temperature, were used as environmental degradation indicators

Keywords: Geomorphology, land-use system, Umbaniun micro-watershed, water quality, water quantity.

RESUMEN

Una cuenca es una unidad geohidrológica que drena en un punto común. Esta unidad natural ha evolucionado a través de la interacción del agua de lluvia con la masa de la tierra, que comprende típicamente de cultivo, las tierras no cultivables y las líneas naturales de drenaje en las zonas de sequía. La producción sostenible depende de la salud, la vitalidad y la pureza de un entorno particular en que la tierra y el agua son componentes importantes. Un estudio piloto se llevó a cabo tanto el estudio de la geomorfología, sistemas de uso de la tierra y su impacto en la gestión de los recursos hídricos en la microcuenca de Umbaniun en Meghalaya. En esta micro-cuenca (3.951,18 ha), el cuerpo de agua tiene una superficie de 5.69ha (0,14%). El presente documento resalta el vínculo entre la geomorfología, usos del suelo y su impacto en la calidad de los recursos hídricos en la microcuenca Umbaniun de Meghalaya. Las características topográficas y físico-químicas, tales como temperatura, el pH, conductividad, oxígeno disuelto, la turbidez y el agua, fueron utilizados como indicadores de la degradación del medio ambiente

Palabras clave: Geomorfología, sistemas de uso de suelos, micro-cuenca Umbanium, calidad de agua, cuantificación de agua.

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Introduction

Watershed management requires physical-graphical information, such as watershed slope, channel network configuration, drainage divide location, channel length and geomorphologic parameters (i.e. relative relief, shape factor, circulatory ratio, bifurcation ratio, drainage density and hypsometric integral - HI) for watershed prioritisation and soil and water conservation measure implementation (Sarangi *et al*., 2004).

Water scarcity has become a major threat to food security, human health and natural ecosystems. Watersheds have two major functions; a hydrological function is concerned with water collection, storage and discharge and watersheds have an ecological function. Human and biological activities on a watershed should be recognised, as should the impact these may have on water, land and forest resources.

Topographical and physical-chemical characteristics are significant in monitoring water quality in relation to watershed land-use systems.

Land-use and land-cover changes play a pivotal role in environmental and ecological changes and have both positive and negative impacts on a particular watershed. They also alter a catchment area's hydrological cycle by modifying rainfall, evaporation and runoff, particularly in small catchment areas (Cao *et al*., 2009).

Meghalaya is endowed with abundant water resources in the forms of springs, streams, rivers and lakes distributed throughout

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the state. Increasing human population and growing urbanisation and industrialisation have led to most of these water bodies gradually becoming polluted. Fresh water bodies are being adversely affected, mainly by deforestation, shifting cultivation and urbanisation. High rainfall and hilly topography have further compounded the problem.

The study area

The Meghalaya Umbaniun micro-watershed covers a 3,951.18 hectare area; it is located at 25o27'29" to 25o32'34" North latitude and 91o47'10" to 91o52'40" East longitude and is underlain by fine, typic Kandihumults loamy-skeletal typic Dystrocherpts soil (Figure. 1). Elevation ranges from 1,600m at its mouth to above 1,960m at the remotest point (point of origin) and it is drained by a 5th order stream. It is dissected by 238 streams of different orders. Different land-use practices prevailing in this micro-watershed have affected the ecosystem to a great extent. It has thus been necessary to take certain steps in analysing natural and anthropogenic processes which will help to maintain its ecological balance.

Materials and Methods

The Umbaniun micro-watershed was divided into three sub micro-watersheds for an in-depth study (sub micro-watershed No. 1, 2 and 3 (Figure 2 to 4). ERDAS Imagine 9.1 GIS software was used for making the supervised classification for studying decade-based change in land-use on the Umbaniun micro-watershed.

Shape parameters

A basin's shape plays a major role in depicting the amount of run-off and sedimentation production rate (SPR). Horton (1932) suggested that erosion rate would be at its maximum in a circular basin and minimum in an elongated basin.

Certain shape parameters (i.e. compactness co-efficient (Cc), rotundity factor (Rf) and circulatory ratio (Rc)) were analysed in the present study to calculate the SPR which could bring about heavy silting in water bodies, thereby leading to their degradation and, ultimately, to their depletion.

The compactness coefficient (Cc) was expressed as a basin's shape as used by Horton. If a basin were a perfect circle then Cc would be equal to 1. A circular basin would have the smallest possible compactness ratio (1.0). It was obtained from the ratio of watershed perimeter to basin area:

$$C_c = \frac{0.282L_p}{A^{0.5}} \tag{1}$$

where Lp was basin perimeter, A was basin area.

Rotundity factor (Rf) was defined as the ratio of basin length to basin area (Chorley *et al.*, 1957). It was calculated using the following equation:

$$R_f = \frac{{L_b}^2}{4A} \tag{2}$$

where Lb was basin length, A was basin area

Circulatory ratio (Rc) was expressed as basin shape used by Miller (1953). This was obtained from the ratio of basin area to basin perimeter using the following equation:

$$R_c = \frac{4\pi A}{{L_p}^2} \tag{3}$$

where A was the basin's area; Lp the basin's perimeter

Sedimentation production rate (SPR) was estimated from the following equation suggested by Jose and Das in 1982:

Log SPR = 4919.80

+48.64 Log (100+Rf)

-1337.77 Log (100+Cr)-1166.64 (4)

Log (100+Cc)

where, SPR = sediment production rate in ha-m/1002 km/year

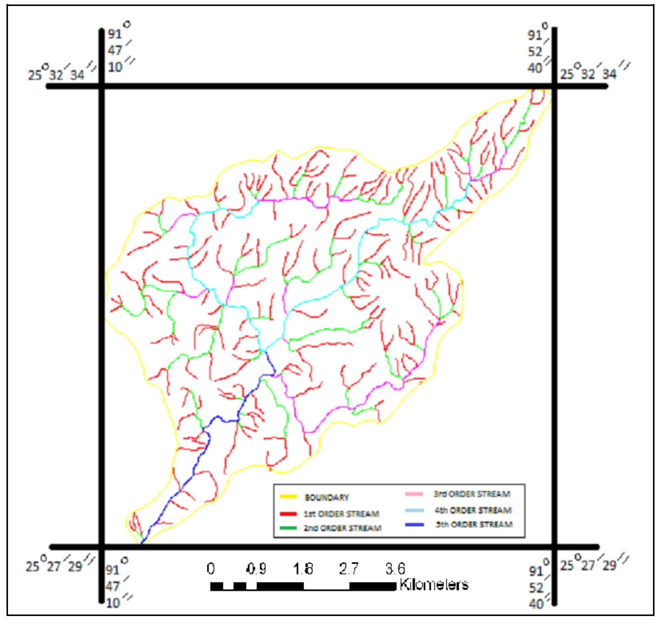

Figure 1. Umbaniun micro-watershed

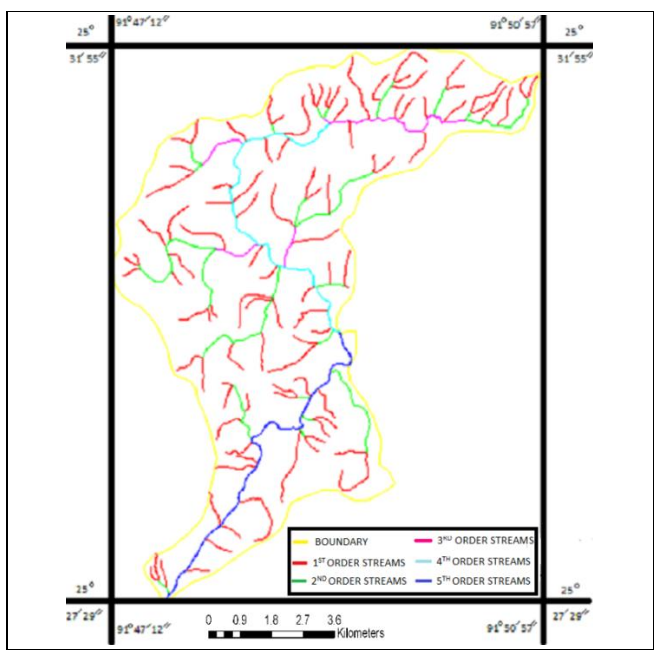

Figure 2. Sub micro-watershed No.1

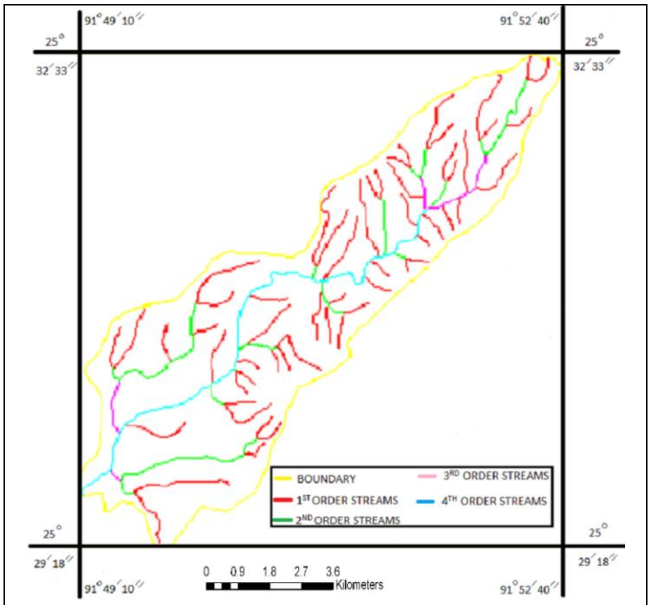

Figure 3. Sub micro-watershed No.2

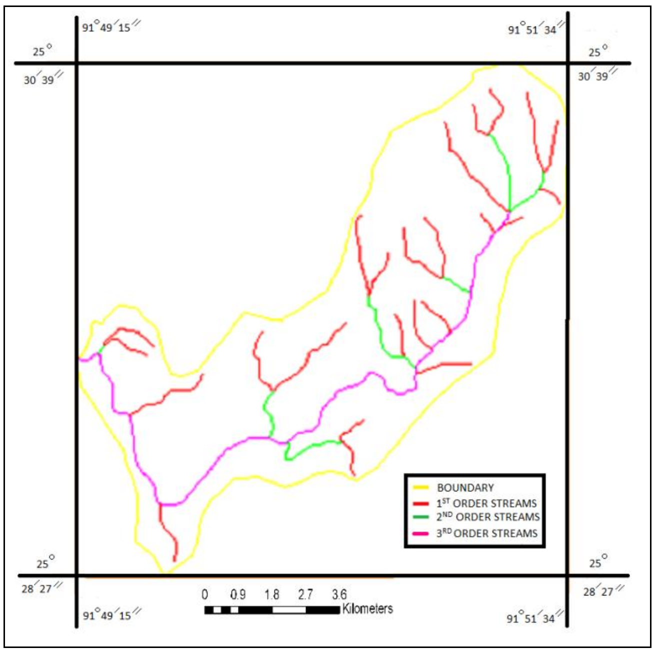

Figure 4. Sub micro-watershed No. 3

Rf = rotundity factor
Rc = circulatory ratio
Cc = compactness coefficient

Micro-watershed slope: Microstation software was used for analysing land slope as one of the important aspects affecting a watershed's normal behaviour and functioning. The whole micro-watershed area was divided into 1 sq km grids; the slope in each grid was calculated by using:

$$\tan\theta = \frac{h}{x} \quad (5)$$

where x = horizontal distance, h = elevation and θ= slope angle.

Land-use systems:

Land-use is known to have a direct impact on water resources; a link between change in land-use systems and water resources was developed in this study. Supervised classification was carried out to study decade-based change in land-use on the Umbaniun micro-watershed (ERDAS Imagine 9.1 GIS software). This method involved ground data re different types of land-use prevailing on the micro-watershed being taken in different polygons by GPS; these polygons were fit in LISS-3 imagery and a land-use map was generated.

Physical-chemical parameters

Physical-chemical parameters regarding land-use system water quality for the Umbaniun Micro-watershed were analysed using standard methods (Maiti, 2001). Data was collected at each sample collection site; conductivity was analysed by Systronics Conductivity – TDS Meter 307, turbidity was measured by EI Digital Turbidity Meter Model-331 and pH and temperature were analysed on the spot by Deluxe Water and Soil Analysis Kit Model-172. Dissolved oxygen was determined by Winkler's Method.

All determinations were the mean of three repeats. The solvents and chemicals used in this study were analytical reagent (AR) grade. The samples were collected during December and January.

Dissolved oxygen

Dissolved oxygen (DO) was analysed using the Winkler method; 250ml of water sample was taken in a bottle. The stopper was removed and 1ml of manganese sulphate solution was added using a pipette; 1ml of alkaline–iodide solution was then added to the sample. The stopper was replaced and the sample was mixed by inverting the bottle several times. The precipitate was allowed to settle for a few minutes. After settling the precipitate, 1ml of concentrated sulphuric acid was added and the bottle was again inverted several times. It was allowed to stand for at least 5-10 minutes. 10ml of the clear fluid was then transferred to a conical flask using starch as an indicator and titrated with 0.025N sodium thiosulphate solution. The DO (mg/L) was calculated using the formula:

$$\text{DO (mg/L)} = \frac{\text{used volume of titrant X 1,000 X 0.2}}{\text{sample volume}} \quad (6)$$

Results and Discussion

Certain shape parameters (i.e. Cc, R¬c and Rf) have been used to estimate the SPR for all three Umbaniun micro-watershed sub micro-watersheds.

The compactness coefficient value for all three sub micro-watersheds was estimated to be greater than 1 (1.64, 1.56 and 1.53 for sub micro-watershed No. 1, 2 and 3, respectively) indicating that all the sub micro-watersheds were elongated. The Rc was found to be 0.37, 0.41 and 0.43 in sub micro-watersheds No. 1, 2 and 3, respectively, showing that they had an elongated shape. This finding was further supported by the Rf where all sub micro-watershed values were greater than 1, thereby concluding that all sub micro watersheds were not circular but more or less elongated in shape, depicting low erosion or SPR (Table1).

Sub micro-watershed No.3 had the highest SPR (3.1 ha-m/100 sq Km/year) followed by sub micro-watershed 1 (2.7 ha-m/100 sq

Km/year) and the lowest SPR was seen for sub micro-watershed 2 (2.6 ha-m/100 sq Km/year).

Table 1. Umbaniun micro-watershed shape parameters

Shape parameter	Sub micro-watershed No.1	Sub micro-Watershed No.2	Sub micro-Watershed No.3
Compactness coefficient (Cc)	1.64	1.56	1.53
Circulatory ratio (Rc)	0.37	0.41	0.43
Rotundity factor (Rf)	2.65	1.78	2.02

Table 2. Sedimentation production rate (SPR) (ha-m/100 sq Km/year)

Shape parameter	Micro-watershed No.1	Micro-watershed No.2	Micro-watershed No.3
Rotundity factor (Rf)	2.65	1.78	2.02
Circulatory ratio (Cr)	0.37	0.41	0.43
Compactness coefficient (Cc)	1.64	1.56	1.53
SPR	2.7	2.6	3.1

Slope is another topographical feature having a considerable effect on a watershed's hydrological pattern. The Umbaniun micro-watershed slope has been classified into six types (Table 3); class 2 slope (moderate slope; 11°–20°) occupied the largest area, i.e. 37.65%, followed by class 1 slope (nearly level to gentle slope; 0o-100) occupying 24.54% of the total geographical area. The least area was covered by class 6 slope (extremely steep slope; > 500). Class 2 and class 1 slope terrains were used mostly for wet cultivation practices (paddy cultivation), whereas jhum has been cultivated on a large scale on terrains having steeper slopes. All above-mentioned practices have led to excessive silting in nearby streams and other water bodies, causing an imbalance in the Umbaniun micro-watershed ecosystem.

Table 3. Different slope classes for the Umbaniun micro-watershed

Slope class	Slope category	Area in hectares	Percentage
00° – 100°	Nearly level to gentle slope	969.6	24.54
110° – 200°	Moderate slope	1,487.6	37.65
210° – 300°	Moderately steep slope	882.9	22.35
310° – 400°	Steep slope	381.5	9.66
410° – 500°	Very steep slope	115.3	2.91
>500°	Extremely steep slope	114.3	2.89

A drastic change in land-use/land cover on the Umbaniun micro-watershed has been found during the last two decades where a vast area of thick pine forest has declined from 2,049.07 ha in 1981 (51.86% total geographical area) to 221.63 ha (5.6% total geographical area) in 2007. A reduction of -1,827.44 ha has been recorded during the last 27 years. This has had a direct bearing on spatial-temporal change in Umbaniun micro-watershed water bodies, reducing rapidly from 6.61% in 1981 to 0.14% in 2007, showing a decline of -255.34 ha (Table 5).

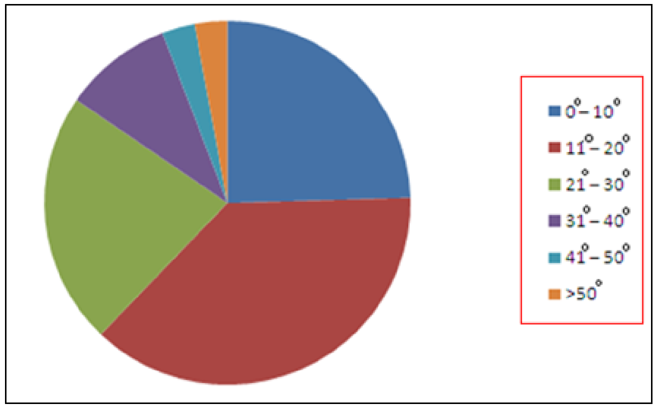

Figure 5. Pie diagram showing slope class distribution on the Umbaniun micro-watershed

Table 4. Decade-based change in a micro-watershed's land-use system

Year	Thick pine Forest (ha)	Open pine forest (ha)	Settlement area (ha)	Agricultural land (ha)	Water body (ha)
1981	2,049.07 (51.86%)	544.21 (13.77%)	465.91 (11.79%)	630.96 (15.97%)	261.03 (6.61%)
1992	1,268.49 (32.10%)	403.85 (10.22%)	548.27 (13.88%)	1,541.41 (39.01%)	189.16 (4.79%)
2004	706.52 (17.88%)	590.21 (14.94%)	1,367.02 (34.59%)	1,276.56 (32.31%)	10.87 (0.28%)
2007	221.63 (5.61%)	679.52 (17.20%)	1,621.96 (41.05%)	1,422.38 (36.00%)	5.69 (0.14%)

Table 5. Changes in land-use system on the Umbaniun micro-watershed over a 27-year period

Land use	Area in ha. in 2007	Area in ha. in 1981	Change over 27 years
Thick pine forest	221.03	2,049.07	-1,828.04
Open pine forest	679.52	544.21	+135.31
Settlement area	1,621.96	465.91	+1,156.05
Agricultural land	1,422.38	630.96	+791.42
Water body	5.69	261.03	-255.34

Table 6. The results of water resources' physical parameters regarding land-use systems on the Umbaniun micro-watershed:

Land-use system	*pH mean± SD	*Temperature (0C) mean ±SD	*Conductivity (μS/cm) mean ±SD	*Turbidity (NTU) mean ±SD	*DO (mg/l) mean ±SD
Settlement	9.8±0.1	7.5±0.152	35.6±2.247	45±3.0	5.155±0.02
Agricultural	4.5±0.2	11.8±0.1	23.2±0.568	42.8±0.60	8.459±0.27
Forestry	5.8±0.43	9.6±0.152	12±2.081	40.6±2.43	9.022±0.06

Controlling physical-chemical characteristics, such as pH, conductivity, dissolved oxygen, turbidity and water temperature, have been used as indicators of degradation in the environment, such studies having increasing during recent years (Tong and Chen, 2002; Sliva and Williams, 2001).

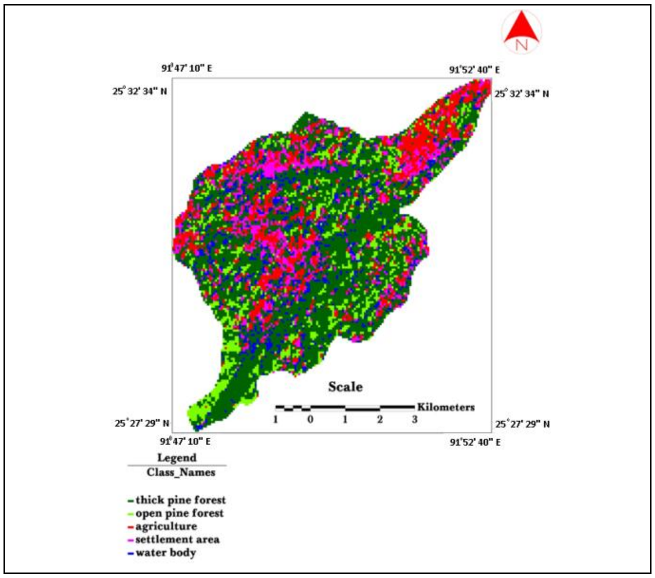

Figure 6. Land-use/land cover on the Umbaniun micro-watershed in 1981

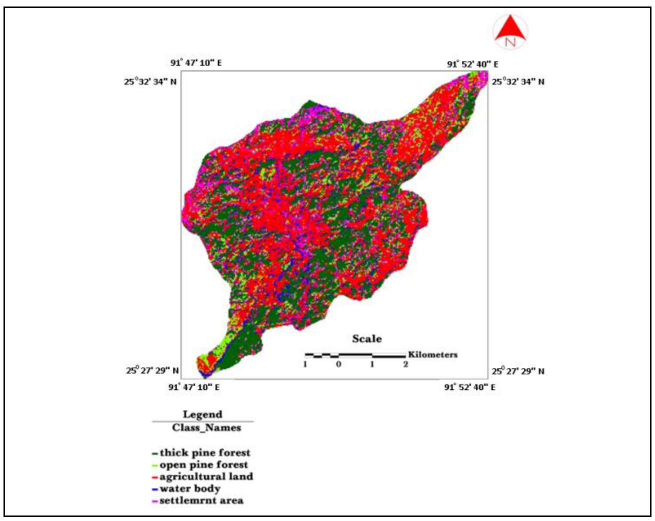

Figure 7. Land-use/land cover on the Umbaniun micro-watershed in 1992

Modern agriculture depends upon adding chemical fertilisers and pesticides to improve production methods. Synthetic fertilisers, in particular, increase agricultural products' yield and productivity by adding excess nutrients to agricultural soils. The relationship between land-use and water quality and water quantity is bidirectional. Land-use activities have a direct impact on water resources, while water quality and quantity greatly influence silting caused by land-use activities. One of the most important contaminants in settlements is domestic sewage which can cause significant pollution.

Watershed water quality in a forested area was better due to no or low human activities compared to that in settlements and agricultural land-use systems. This could be confirmed by the low turbidity and conductivity, and high dissolved oxygen (DO) in a forested area. The electric conductivity of the water samples gave the samples' total ion content. Conductivity and turbidity were found to be higher in the streams near settlement areas, indicating reduced water clarity and the presence of high ion concentrations due to low vegetation cover and increased human activity. However, they were found to be considerably high in agricultural land-use systems which could have been attributed to erosion and micronutrient leaching from the soil. Turbidity was high in settlement and agricultural lands due to the vast range of chemicals used. Irrigated agriculture has an impact on water quality through the use of agrochemicals, excessive water abstraction and evaporative loss. Water quality degradation in agricultural regions can be attributed to the transportation of eroded soil and improper waste disposal.

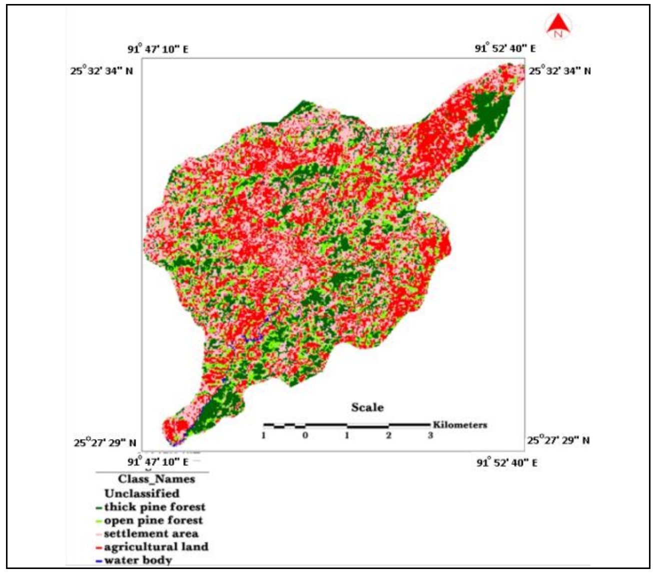

Figure 8. Land-use/land cover on the Umbaniun micro-watershed in 1992

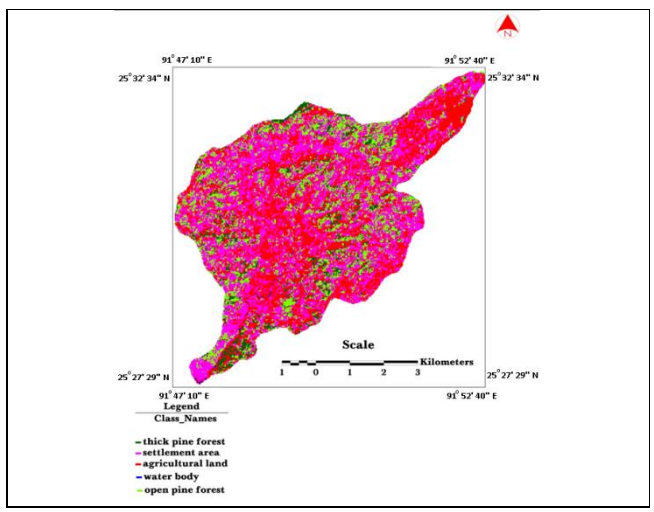

Figure 9. Land-use/land cover on the Umbaniun micro-watershed in 1992

Natural turbidity levels will vary with flow and geographical location. Studies have indicated that sheet, riverbank and gully erosion are also major contributors to turbid waters. This can have adverse effects, such as increased load nutrients from sediments and reduced penetration of light thereby having an adverse impact on aquatic life's ecological systems (Agriculture and Resource Management Council of Australia and New Zealand, 2000). Degraded water quality in settlement areas can be attributed to the breaking of septic tanks and seeping sewerage systems in rural communities, particularly those associated with on-site domestic wastewater systems. Conductivity was found to be substantially low in forest areas compared to settlement and agricultural land-use systems, owing to less ion concentration release into water.

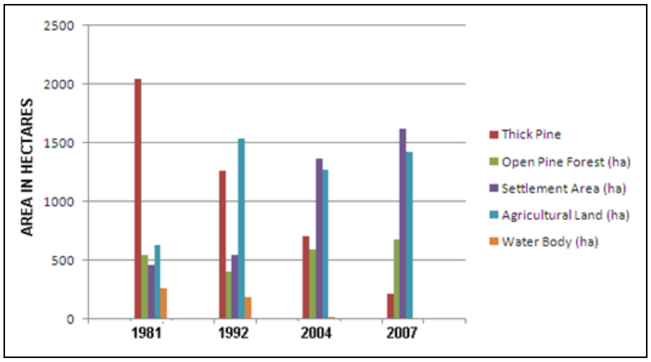

Figure 10. Graphical representation of decade-based change in land-use systems on the Umbaniun micro-watershed

Dissolved oxygen (DO) plays a key role in assessing water quality and checking stream pollution The maximum amount of oxygen that can be dissolved in water also depends on the amount of other substances (such as salts) dissolved in the water. Substances dissolved in water take up space between water molecules which could otherwise be occupied by oxygen Thus, the DO level in water from a stream surrounded by a settlement area was found to be low (5.155 mg/l) thereby posing a threat to aquatic life compared to that of agricultural and forest land-use systems, found to be 8.459 mg/l and 9.022 mg/l, respectively. Agro-chemicals used by farmers, such as fertilisers and pesticides, were being released to ground and surface waters by agricultural practices, thereby lowering the pH to 4.5, indicating that the water resource in agricultural land-use systems was acidic whereas in settlement land-use, due to the excessive release of detergents, the pH had increased to 9.8, indicating the high alkalinity of the water regarding this land-use. The variation in temperature in the three land-use systems ranged from 7.5 to 11.8 0C.

Land-use had a significant impact on water resources. Thus, increased human activities and over-exploitation of land resources has led to a decline in the quantity and quality of water resources.

Conclusion

A watershed is defined as a 'complex and dynamic ecosystem in which natural processes occur, agricultural and/or industrial activities take place and people interact with each other and with their natural environment, the boundaries of which being based on topography and the location of streams.' Slope has a considerable impact on a watershed's hydrological balance. The steeper

the slope, the greater the SPR, thereby affecting water bodies' overall behaviour. Over-exploitation of land resources like felling trees for jhum cultivation, collecting timber, collecting firewood, extensive farming, stone and sand quarrying, etc on the Umbaniun micro-watershed has led to a decline in both the quantity and quality of its water resources. Land-use and water resources have a direct co-relationship, where forest having low human interference had better water quality compared to settlement and agricultural areas due to developmental activities; overall water quality was better in forest areas due to less human intervention. Humans' improper practices have led to decreased water quality in agricultural and settlement areas. There is thus an urgent need to regulate land-use practice on the micro-watershed to conserve and manage its precious soil and water resources to maintain a healthy and stable environment for the sustenance of society.

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