DEPICTING ECOLOGICAL CONSEQUENCES THROUGH LANDSCAPE INDICATOR APPROACH

Sangitarani Nayak*, S K Srivastava, R N Sankhua****

* Banasthali University, Rajasthan

** National Water Academy, Pune

ABSTRACT

Understanding ecological consequences through landscape indicator is a primary challenge. Changes in land use and land cover drastically affect the ability of ecosystems to provide essential ecological goods and services, which in turn, affect the economic, public health, and social benefits that these ecosystems provide. One of the great scientific challenges for geographic science is to understand and regulate the effects of land cover change and the complex relationship between human and environmental system. Landscape ecology provides theories to strengthen assessments. Geographic Information Systems (GIS) supply tools to implement them, such as landscape indicators - quantitative measurements of environmental condition or vulnerability for an area or watershed. Producing landscape indicators can be complex, lengthy, and require substantial GIS expertise. In this paper, the Pimpri-Chinchwad-Municipality-Corporation (PCMC) area has been analyzed using patch analysis for the secondary abstraction of landscape characteristics and presented in subsequent paragraphs.

Keywords: Ecosystem; environment; landscape; watershed;

INTRODUCTION

Water quality and ecosystem management should integrate multiple scale assessments encompassing basic, local-scale investigations to complex, multiple-stressor regional analyses. Landscape ecology provides theories to strengthen assessments. Geographic Information Systems (GIS) supply tools to implement them, such as landscape indicators - quantitative measurements of environmental condition or vulnerability for an area or watershed. Producing landscape indicators can be complex, lengthy, and require substantial GIS expertise. ATtILA is a GIS extension that accepts disparate data sources and is suitable across diverse landscapes, from deserts to rain forests to urban areas. The extension includes four families of indicators: landscape characteristics (percent forest cover), human stresses (population change and road/stream crossings), riparian characteristics (percent crop land within 30 meters of streams), and physical attributes (elevation range). Within each group users can select indicators to calculate, choose input data, and modify selected assumptions. Display options include: maps of areas ranked by individual indicator values or multiple indicator weighted indices, and bar charts.

Multiple scale examples depict uses of landscape factors for: describing ecological regions of the Pune, exploring synergistic utility of PCMC's ecological regions and hydrologic units, targeting restoration needs sub-watersheds, and describing road and riparian influences on sedimentation in the watershed. Landscape indicators are readily available and should become integral for water quality assessments.

Many of today's water quality problems stem from human uses of and impacts on landscapes. Solving these problems through restoration will depend on understanding the processes and links between landscape activities and subsequent stresses to and impacts on aquatic systems. As our understanding of aquatic ecosystems increases through integration of multiple measures of aquatic health including: chemistry, biological communities, habitat structure, channel geomorphology and hydrology; we are also beginning to recognize the need to better describe and understand the myriad landscape practices and stresses that affect our waters. Advances in landscape ecology and Geographic Information Systems (GIS) techniques have made landscape factors viable tools for targeting water quality concerns. Landscape measures are proposed as one of the critical ecological indicators for nationwide application. A wide array of environmental protection efforts has a continuing need to quickly and economically characterize important landscape factors affecting watersheds and ecological regions at many scales. These include community based environmental protection projects, watershed restoration projects, water quality standards development (including bio-criteria, nutrient criteria and others), TMDL (Total Maximum Daily Load) screening and development efforts, non-point source (NPS) identification and modeling efforts, and wide area statistical surveys of water resource integrity.

Landscape ecology incorporates the study of biological, physical, and societal causes and consequences of spatial variation in landscapes. Landscape structure is determined by complex interactions of physical, biological, political, economic, and social factors. Most landscapes have been influenced by anthropogenic disturbances, and the resulting landscape mosaic is a mixture of natural and human-managed patches that vary in size, shape, and arrangement.

EARLIER RESEARCH

The landscape indicator analytical approach is derived from the relatively new field of Landscape Ecology which began to emerge as a specific scientific discipline in the late 1980s (Golley 1987). This ‘landscape approach, combines critical analytical concepts from the disciplines of geography, landscape ecology, and hydrology in conjunction with remotely sensed and other geographic data in a spatially-explicit geographic information system analytical framework (Jones et al., 2000, Pitchford et al. 2000, O’Neill et al., 1997). The emergence of the landscapes approach coincided with two other important technological developments that are promoted by the USGS geographic science; i) the widespread availability of GIS technology, and ii) the availability of moderate resolution, synoptic land use and land cover data. Early German *Landschaftkunde* (landscape geography) studies often focused on small unique areas and thematic regions (Holt-Jensen 1988) and Carl Sauer once proposed landscapes as a basic unit of geographic inquiry (Sauer 1925).

OBJECTIVES OF THE STUDY

Because of increasing need to monitor ecosystem health and due to the traditionally high costs associated with the field based monitoring, alternatives to the traditional monitoring approach have been developed using high resolution remotely sensed data, standard geographic data, and derived products. Landscape indicator approach applies to a combination of concept from landscape ecology, hydrology, geography with remotely sensed data and spatial data and GIS technology to the assessment of landscape and ecological conditions. The main objectives of the study are:

i) To do the patch analysis of the landscape
ii) Development of landscape characteristics metrics
iii) Development of riparian characteristics metrics
iv) Development of human stress metrics
v) Development of physical characteristics metrics

THE STUDY AREA

The PCMC area has been taken as the area of study.

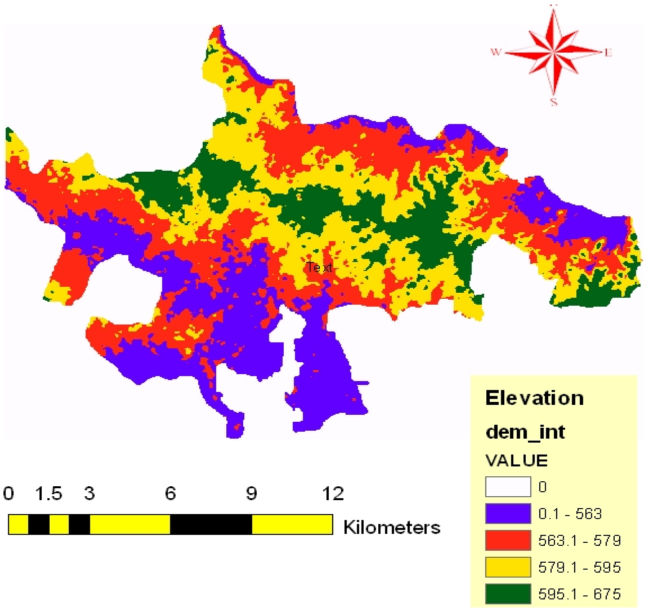

Figure 2-DEM of the study area

MATERIALS AND DATA USED

The IRS LISS III satellite image of December, 2008 is classified using supervised algorithm. Six types of land use patterns are identified in the entire study area, which includes agriculture, crop land, forest, scrubland, settlement and water. The ASTER DEM of 30 m resolution is downloaded from aster site. Land use and land cover data in a raster format is prepared.

Soil map published by National Bureau of Soil Survey and Landuse Planning (scale 1:5,00,000) are used. In order to execute landscape indicator metrics, the, landuse/land cover, soils, geology are derived using various thematic maps and verified with field data. The hydraulic soil group (HSG) of the study area is derived from prevailing National Bureau of Soil Survey (NBSS) soil maps. The soils of the study area fall in B, C and D hydrological soil groups. The B type soil is of loam, C type soil is sandy clay loam and D Fine, Clay type of soil. The streams are delineated using GIS and presented in a vector format. The transportation network of roads and transportation data in a vector format are prepared. Also the data from field sampling or a monitoring network, such as Water quality data, population data, etc are prepared taking data from PCMC. Other GIS data layers targeted for a specific ecological consequence like boundary map, derived land use and land cover are also made use of in the study.

METHODOLOGY

Appropriate geographic analysis units for aquatic ecosystem studies of the PCMC area crucial to enhance understanding of important processes. Both ecological regions and watersheds are essential geographic frameworks necessary to describe, diagnose, and eventually, predict landscape influences on water resources. In this study, the GIS approaches for simultaneously using ecological regions and watersheds to describe and eventually understand aquatic ecosystem patterns and processes are made use of. Ecosystem and ecological attributes like biotic and abiotic characteristics, human systems as a biotic influence, and multiple scales vs. only small areas. Many successful applications have resulted from classification approaches that delineate ecologically distinctive areas resulting from the mesh and interplay of the geologic, land-form, soil, vegetative, climatic, water and human factors.

ATtILA has been used to calculate many landscape metrics. Four metric groups are included in the study: landscape characteristics, riparian characteristics, human stressors and physical characteristics. There are also four display options to view metric results.

Landscape data, analysis tools and the information embodied in landscape factors are increasingly available to fill this knowledge gap. Analytical Tools Interface for Landscape Assessment uses readily available land cover and other spatial data to summarize and map over 50 landscape factors thought to be important to water quality concerns. *Landscape Characteristics* available through land use/land cover data such as MRLC (Multi-Resolution Landscape Characterization), Available analysis boundaries (based on polygons/shape files) are used including watersheds, hydrologic units, ecological regions, Slope based factors also rely on slopes derived from digital elevation models (DEM's). The slope based factors are flexible; the user may specify desired slopes. Total area is also calculated for each factor. The flow chart of methodology is presented in the Figure 1. Landuse map of the study area and the tool interface are depicted in Figures 2 and 3.

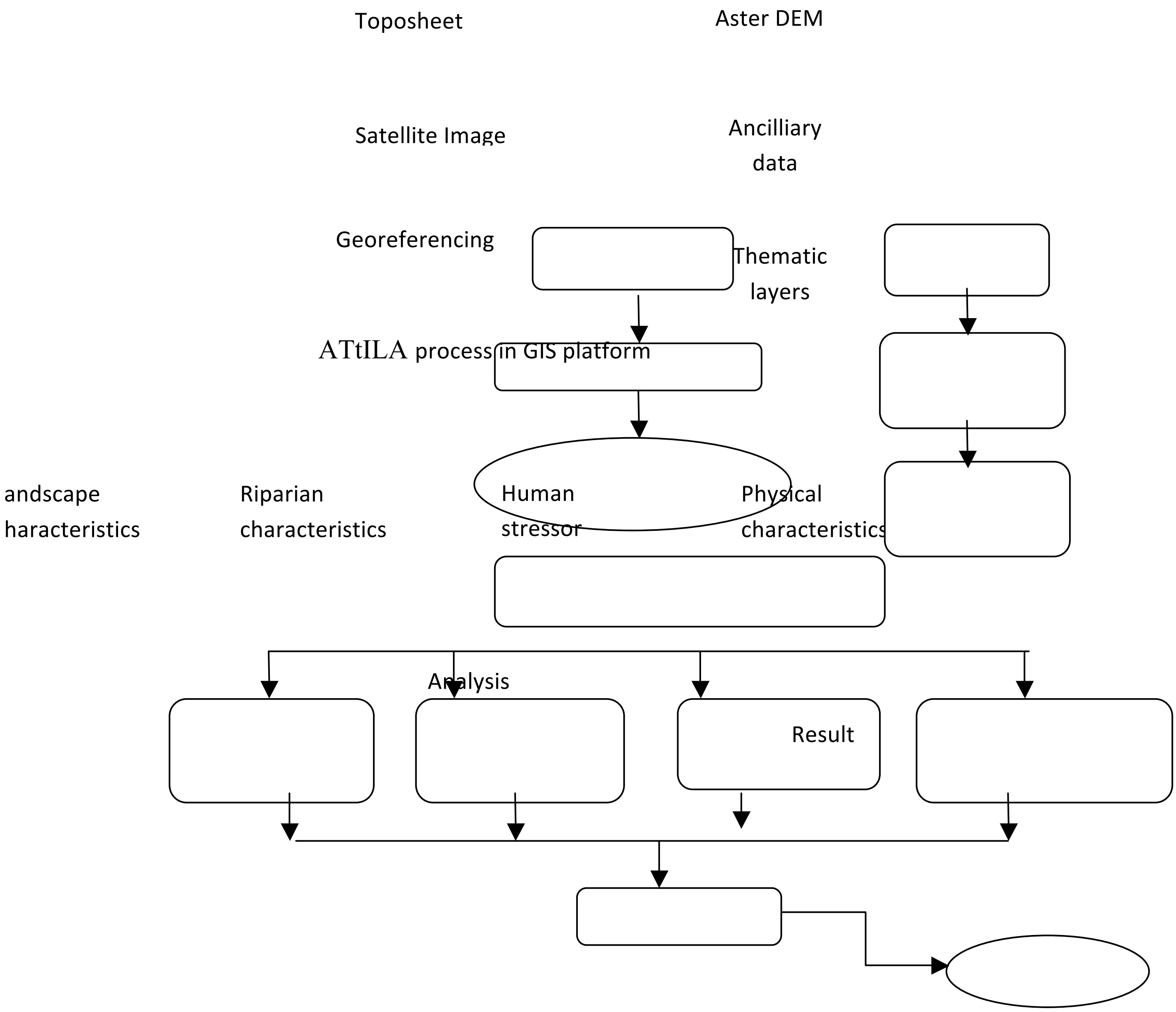

Figure- 1 Conceptual components and processing sequence of ATtILA process

Characteri
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metrics

General and
specialised tools

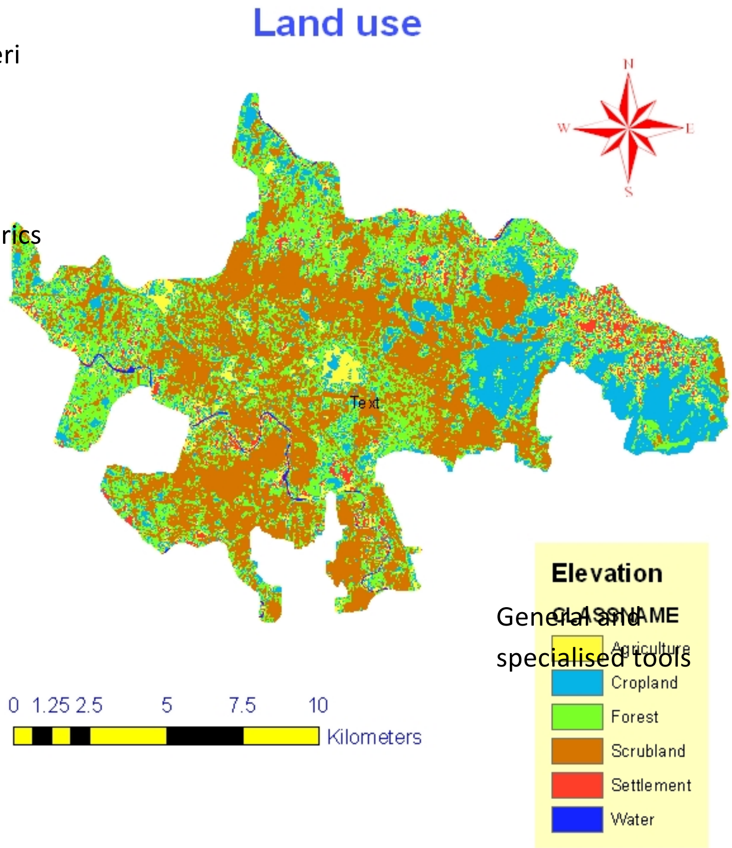

Figure 2 Landuse map of Pune area

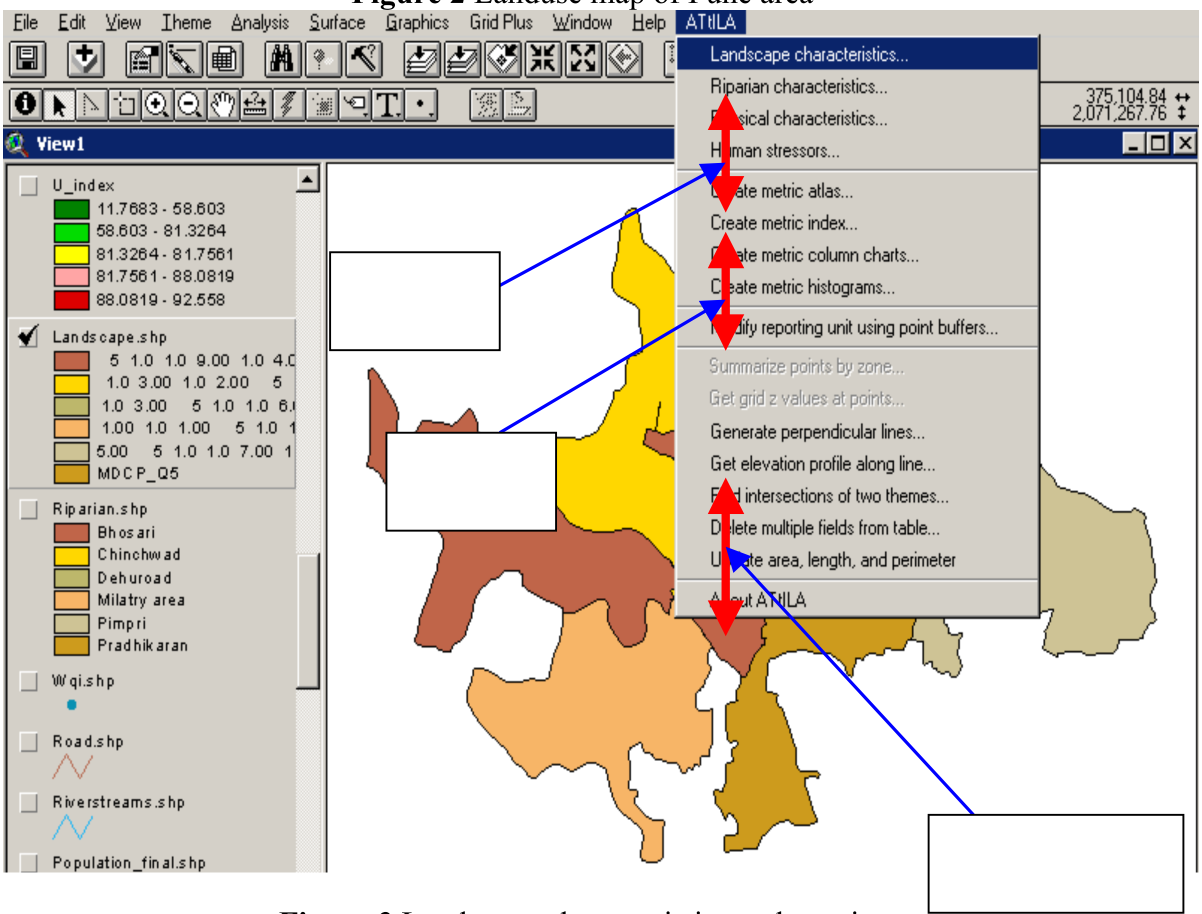

Figure 3 Landscape characteristics and metrics

RESULTS AND DISCUSSIONS

The following results have been emerged from the study of Pimpri-Chinchwad-Municipality-Corporation (PCMC) area and are briefly narrated with some of the important results. These imply: i) Geographic analysis of spatially explicit patterns of ecological characteristics (for example, riparian zones near streams) to construe ecological conditions, ii) Concepts from landscape ecology relating changes in landscape patterns to changes in ecological processes, iii) Hierarchy theory that analyzes the consequences of landscape change on ecosystems at multiple scales, iv)Spatially explicit digital data and maps of biophysical and cultural characteristics and human use to interpret landscape patterns relative to ecological conditions, v) Inclusion of humans as part of the environment.

Different characteristics metrics of the result are cited as below along with few of the important characteristics in the following Tables.

Landscape Characteristics derived are presented in Table 1.

AgpSL - Agricultural pasture on steep slopes

AgtSL - Total agricultural land use on steep slopes

Usr1SL - User defined class on steep slopes

Table 1 Major Landscape Characteristics

Name	Area(km^2)	AGPSL9	AGTSL9	User defined
Bhosari	31.17	3	3	None
Chinchwad	38.12	4	5	-
Dehuroad	38.26	4	5	-
Military area	0.33	0	0	-
Pimpri	23.49	3	4	-
Pradhikaran	34.69	3	3	-

Riparian Characteristics in respect of the following are also derived from the PCMC data set in respect of the following and presented in a tabular form. (Table-2).

Ragc - % of stream length adjacent to cropland

Ragp - % of stream length adjacent to pasture

Ragt - % of stream length adjacent to all agricultural use

Rbar - % of stream length adjacent to barren

Rfor - % of stream length adjacent to forest

Rurb - % of stream length adjacent to urban

Rusr1 - % of stream length adjacent to user defined class

Rwetl - % of stream length adjacent to wetland

Rnat - % of stream length adjacent to all natural land use

Rhum - % of stream length adjacent to all human land use

Table 2 Major Riparian Characteristics

Name	Area(km^2)	**N_index**	**Pfor**	**Pfor_a**	**Pshrb**	**Pshrb_a**
Bhosari	31.17	18.6736	3.5728	1113600	15.100	4706800.0
Chinchwad	38.12	18.2439	9.361	3568100	8.8830	3385900.0
Dehuroad	38.26	41.3970	3.986	1525400	37.410	14315400.
Milatry area	0.33	88.2317	5.304	17400	82.926	272000.0
Pimpri	23.49	7.4420	2.150	505200	5.2916	1243200.0
Pradhikaran	34.69	11.9181	4.229	1467100	7.6890	2667300.0

Human Characteristics – Table 3 depicts the results of human characteristics

P_LOAD - Phosphorus loading, N_LOAD - Nitrogen loading, POPDENS - Population density, POPCHG - Change in total population, PCTIA_LC - Impervious cover, based on land use, RDDENS* - Road density by road class, RDLEN* - Total road length by class, STXRD* - Number of road/stream crossings by road class, PCTIA_RD - Percentage of impervious cover, based on road density, and STPRD* - Length of roads in close proximity to streams (user defined distance) by class

Name	Popdens1	Popudd	Popdens2
Bhosari	61405.650	80506.56	1.000
Chinchwad	38882.297	2291121.13	0.996

Dehuroad	10769.375	189514.46	0.971
Military area	15390.137	869587.94	0.979
Pimpri	14464.808	122261.87771	0.970
Pradhikaran	5698.658	154108.21450	0.983

Physical Characteristics are also derived for the PCMC area.

PRCPRNG - Precipitation range, PRCPMIN - Minimum precipitation, PRCPMAX - Maximum precipitation, PRCPMEAN - Average precipitation, PRCPSTD - Standard deviation of precipitation, ELEVRNG - Elevation range, ELEVMIN - Minimum elevation

ELEVMAX - Maximum elevation, ELEVMEAN - Average elevation, ELEVSTD - Standard deviation of elevation, SITE_ELEV - Elevation at point locations ,SLPRNG - Slope range, SLPMIN - Minimum slope,SLPMAX - Maximum slope, SLPMEAN - Average slope, SLPSTD - Standard deviation of slope,STRMDENS* - Stream density, and STRMLEN* - Total stream length

Gridcode	Class	Area	Perimeter
51	Water	1311061.18	58004.76
11	Residential	58924531.01	1884033.08
24	Other Agri.	17597536.79	1201268.52
21	Cropland	56502937.31	3348653.45
43	Forest	8452367.668	611895.85
32	Scrubland	27042895.61	942408.59

CONCLUSIONS

In this spatial analytical study, consequences are developed by integrating key spatial data sets in a GIS environment and by developing a suite of per-pixel landscape indicators at an aggregate and more synoptic scale of analysis from two or more temporal lu/lc data. These landscape indicators are then run through endpoint-specific models to identify increases or decreases in the quality of specific ecological characteristics. The range of modeled statistical values are mapped into a range of classified values and displayed in a spatially-explicit GIS environment. Land degradation and desertification processes represent a serious problem in many areas. The dominance of any one or a number of these factors varies with the given ecological land unit. PCMC's eco-regions' agriculture, forestry, etc. resulted in characteristic patterns of human disturbance over time. Cumulative human disturbances yielded a suite of risks to aquatic systems that is eco-region specific. Eco-regions can be used as reporting frameworks that clarify patterns of environmental data (such as nutrient transport) reflecting both natural and human influences. This allows development of management strategies appropriate to regional expectations, and thus, define areas where standardized management practices can be applied after being proven in individual sites or watersheds.

REFERENCES

1. Booth, D.B. and Jackson, C.R. 1994. Urbanization of aquatic systems - degradation thresholds and the limits of mitigation. Effects of Human-Induced Changes on Hydrologic Systems - American Water Res. Association. June 1994. pp. 425-434. [U]
2. Bryce, S.A., Larsen, D.P., Hughes, R.M. and Kaufmann, P.R. 1999b. Assessing relative risks to aquatic ecosystems: a Mid-Appalachian case study. Journal of the American Water Resources Association. 35(1). pp. 23-36.
3. Bryce,S., Omernik, J.M., and Larsen, D.P. 1999a. Ecoregions: a geographic framework to guide risk characterization and ecosystem management. Environmental Practice. 1:141-155.
4. Center for Watershed Protection. 1998. Rapid watershed planning handbook: a comprehensive guide for managing urbanizing watersheds. Ellicott City, MD. 11 chapters plus appendices.
5. Cowen, D.J., and Jensen, J.R. 1998. Extraction and modeling of urban attributes using remote sensing technology. In: People and Pixels: Linking Remote Sensing and social Science. Diana Liverman, Emilio F. Moran, Ronald R.
6. O'Neill, R.V., Hunsaker, C.T., Jones, K. B., Riitters, K.H. , Wickham, J.D., Schwartz, P.M.,Goodman, I.A., Jackson, B.L. and Baillargeon, W.S. 1997. Monitoring environmental quality at the landscape scale. Bioscience, v. 47(8) p. 513-519.
7. USEPA. 1994. Landscape Monitoring and Assessment Research Plan. U.S. Environmental Protection Agency, Washington, D.C. EPA 620/R-94/009.