Land Degradation Modeling in Dal lake Catchment Using Geospatial Tools

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ABSTRACT:

Soil erosion is a complex dynamic process by which productive surface soils are detached, transported and accumulated in a distant place resulting in exposure of subsurface soil and sedimentation downstream. Soil erosion in catchment areas and its subsequent deposition in rivers, lakes and reservoirs are of great concern to humanity. The soil erosion upstream results in the loss of reservoir capacity as well as degradation of water quality downstream. Picturesque fresh water lakes in Jammu & Kashmir, particularly the well known Dal Lake in Srinagar, is facing eutrophication problem due to soil erosion in the catchment area. The Dal Lake is of great tourist and economic importance for the people of the Kashmir valley. The Dal Lake which has shrunk in dimensions, from 25 sq. km in past century to less than 11 sq. km now is fighting a loosing battle against rampant pollution and sedimentation. As a pilot study, the Dal Lake watershed spread over an area of 337 sq. km was taken up for soil erosion study using remotely sensed data, GIS and simulation modeling. The study utilized different types of data including Survey of India topographic maps for generating DEM of 40 meter resolution, soil map, Landsat TM & ETM satellite data and the field observations. Two date Landsat image, 1992 and 2001, were used for generating the land use/land cover map of the study area and to detect the changes between these two time periods. The various land use and land cover classes identified include agriculture, orchards, plantation, mixed forest, evergreen forest, degraded forest, Built up, meadows, lake vegetation, pasture, river boulders, clouds, shadow, bare rock, fallow, barren and open water. The classes dominating in Landsat 1992 are mixed forest (20.26 % area), degraded forest (11.75 % area), plantation (10.52 % area) and pasture (9.01 % area). Agriculture and built up covers 5.93 % area and 1.68 % area respectively. In Landsat 2001 the dominating classes are mixed forest (20.42 % area), pasture (10.18 % area), degraded forest (10.12 % area) and plantation (9.54 % area). Built up and agriculture covers 6.21 % area and 3.53 % area. The Kinematic Runoff and Erosion model KINEROS2, was used for evaluating the effect of land use/cover change on runoff and erosion. Surface runoff, peak sediment discharge and total sediment yield were simulated using the KINEROS2. The results show; 0.3 (mm) - 0.27 (mm) min. increase in runoff, 400 (kg) – 5000 (kg) average increase in peak sediment yield, 2500 (t/ha) – 3000 (t/ha) average increase in sediment yield in Planes & Channels respectively from 1992-2001. The results have identified areas where runoff and erosion are increasing as well as areas where the production of these processes have decreased (though marginally). It is hoped that these results would facilitate the prioritization of the micro-watershed in the catchment so that corrective and mitigation measures are taken to arrest the land degradation in the watershed.

1. Introduction:

Soil erosion is a complex dynamic process by which productive surface soils are detached, transported and accumulated in a distant place resulting in exposure of subsurface soil and sedimentation in reservoirs. It is estimated that out of the total geographical area of 329 Mha of India, about 167 Mha is affected by serious water and wind erosion. This includes 127 Mha affected by soil erosion and 40 Mha degraded through gully and ravines, shifting cultivation, waterlogging, salinity and alkalinity, shifting of river courses and desertification (Das, 1985).

Narayan and Babu (1983) have estimated that in India about 5334 Mt (16.4 t ha−1) of soil is detached annually, about 29% is carried away by the rivers into the sea and 10% is deposited in reservoirs resulting in the considerable loss of the storage capacity. The entire Himalayan region is afflicted with a serious problem of soil erosion and rivers flowing through this region transport a heavy load of sediment. The Himalayan and Tibetan regions cover only about 5% of the Earth's land surface, but supply about 25% of the dissolved load to the world oceans (Raymo and Ruddiman,1992).

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Soil erosion in catchment areas and its subsequent deposition in rivers, lakes and reservoirs are of great concern to humanity for two reasons. First, rich fertile soil is eroded from the catchment areas, reducing them to poverty. Secondly, loss of reservoir capacity occurs, as well as degradation of downstream water quality. Although sedimentation occurs naturally, it is further aggravated by poor land use and land management practices adopted in the upland areas of watersheds. Uncontrolled deforestation due to forest fires, grazing, incorrect methods of tillage and unscientific agricultural practices are some of the bad land management practices which accelerate soil erosion, resulting in large increase of sediment in flow into the streams (NIH 1985).

Who has not heard of the Vale of Kashmir and it's limpid fresh water lakes, especially the well known Dal Lake that imparts frame and freshness to the environs or its capital city of Srinagar. Besides supporting tourism, Dal Lake is also important for fishery, drinking water and aquatic sport. It is this very abode of ideal happiness that is now in the very jaws of its extinction. The Dal Lake which has shrinked in dimension (size and depth) attained various shapes from time to time by natural and man induced causes.
Over the years, urbanization, land-use changes, sedimentation, human settlement, flow of fertilizers and pesticides from the catchment and encroachment of the lake area have resulted in environmental issues which may be very difficult to resolve. The overcrowding and affluent populace has, for it's greedy and selfish ends, denuded the environment around the lake in such a manner that no authority and amount of wealth can save it from it's extinction. The only hope lies within the spirit and psyche of the populace itself.

It is well known that large quantities of silt flowing into the lake through Telbal Nallah originate from two main sub watersheds Dara-Danihama & Dachigam. As a result, the northern basin is partly filled reducing its useful age. The reduction of water depth due to siltation has reduced water volume and impacted thermal stability. The present silt load to the lake is 60,877 tons per year (Zutshi and Yousuf, 2000). So, sedimentation being one of the main factors in the reduction of size and depth of Dal Lake, it is important to study its assessment with the changes in land use/land cover. The present research will quantify the impact of land use/land change in the sedimentation yield and the runoff of the catchment.

The Kinematic Runoff and Erosion model KINEROS2, which is based on first principals (i.e., physics based), is suitable for evaluating the effect of land use/cover change on runoff and erosion in small watersheds (Smith et al. 1995). In spite of its limitations, successful applications of this model to gaged watersheds have been reported in the literature (Osborn and Simanton 1990, Goodrich et al. 1994, Smith et al. 1999, Ziegler et al. 2001, Kalin et al. 2003, Kalin and Hantush 2003). The present study, presents an application to the event-based model KINEROS2 to simulate runoff and sediment discharge as a function of land use / land cover change in a sub watershed of the Dal lake catchment.

2. Location of the study area:

Dal Lake (Fig. 1) is situated at an altitude of 1583 m above MSL to the northeast of Srinagar, the summer capital of Jammu and Kashmir State. One of the significant features of Dal Lake is its vast and diverse catchment which is located in between 74° 48’ & 75° 08’ E and 34° 03’ & 34° 13’ N. This area is surrounded by Sindh basin in the north and Jehlum basin in the south.

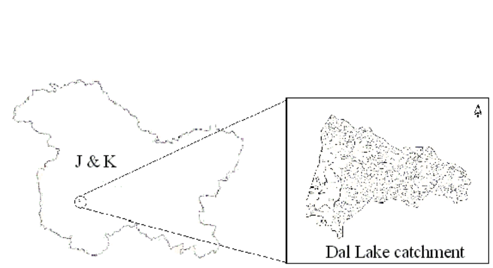


Fig. 1 Location map of the study area

Kashmir province of Jammu and Kashmir has cold moist winters and a mild temperature in the summers. The Kashmir in particular is very less affected by the monsoons, local rains in Lake Catchment during summer is a prominent feature. The climatological data including temperature and rainfall were obtained from stations, which are located in and around the study area. In the study area the temperature varies between a monthly mean maximum of 31 C° in July and a minimum of -4 C° in January with an average of 11 C°. The annual rainfall per annum at Srinagar is 650 mm and at Dachigam 870 mm. An average of 600 mm of snow falls in Srinagar during the winter but the snowfall on the higher slopes is much heavier.

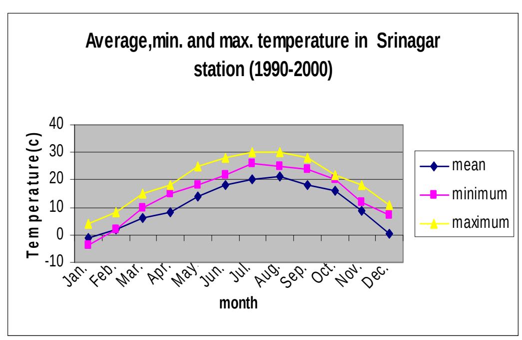


Fig. 2 Average, min. and max. temperature

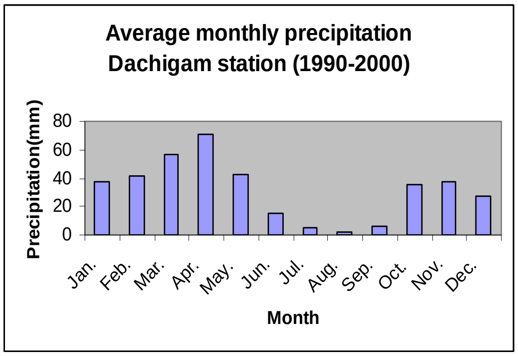


Fig. 3 Average monthly precipitation

3. Data Sources:

In the study, a variety of data including satellite images Landsat ETM and Landsat TM, digital elevation model, soil map, standard 1:50000 scale SOI topographic maps, hydrometeorological data and various thematic maps obtained from various sources have been used as data sources together with ground truth studies that have also been carried out.

4. Methodology:

4.1. Digital elevation Model:

Digital Elevation Model (DEM) is a representation of the continuous variation of relief over space that helps in assessing landscape characteristics along with topography and has a wide application in hydrological modeling. These characteristics help to determine slope steepness, slope length, flow direction, areas, boundaries and outlets of watersheds. For generating DEM the SOI topographic maps at 1:50,000 scales with 40m contour interval, of the study area were digitized in PCI Geomatica V9.0.

4.2. Land use/Land cover:

Land use is an important watershed surface characteristic that affects infiltration, erosion, and evapotranspiration. Thus, almost any physically based hydrological model uses some form of land use data. Land cover is an important input parameter for a number of hydrological, erosion and ecological models, which constitute necessary tools for development, planning and management of natural recourses in the territory. Remote sensing offers valuable tools for obtaining land use/land cover information. With improvements in software and hardware and decrease in the cost of imagery, satellite remote sensing is being used for more and more studies particularly at the landscape level. The characterization of land cover from satellite data has conventionally provided a means of assessing a large geographical area with limited time, and resources.

4.2.1 Image classification:

Image classification procedures are used to classify multispectral pixels into different land cover classes. The input for the classification is multispectral bands and textural patterns computed from the multispectral data. Primary methods are supervised classification and unsupervised classification. In the unsupervised approach, pixels are grouped into different spectral classes by clustering algorithms without using prior information (Jenson, 1996). Unsupervised classification algorithms only have a secondary role in remote sensing. Supervised classification begins with ground observations at particular points in the study area.

ERIDAS IMAGINE 8.4 image processing software, used for present research supports both supervised and unsupervised classification. We opt for a combination of both the techniques. The approach we have followed is depicted in the Fig. 4. ISODATA, an unsupervised classification technique was used in order to group the pixels into clusters. 100 spectral clusters with 95% convergence value were selected with the aim of performing unsupervised classification. Unsupervised classification signatures were gathered to isolate large areas of uniform land covers. Of the 100 original signatures, approximately 17 proved valid and were retained through the remainder of the classification process.

Training sites were necessary to define classes that did not get classified uniquely during the unsupervised classification. Generally supervised classification has three distinct stages namely training, allocation and testing.

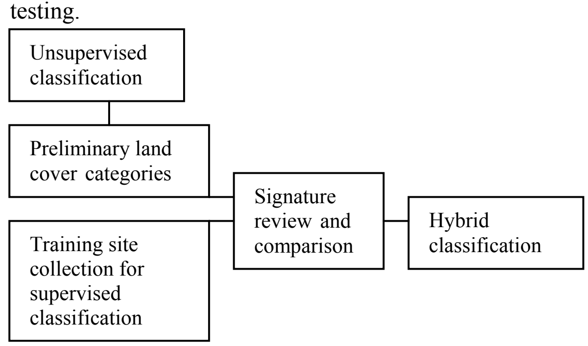


Fig.4. Steps involved in developing a hybrid classification

4.2.2 Collection of training sites:

Training sites were necessary to define classes that did not get classified uniquely during the unsupervised classification. Training sites were created by demarcating a polygon or area of interest for the known cover types. Training sites were collected for all land cover classes. Training site selection was facilitated by the availability of Ground truth information.

4.2.3 Signature Development:

In signature development, training area statistics were gathered for each spectral band to be used in the final classification.

4.2.4 Classification:

Data were classified through a Maximum likelihood classifier decision rule. The Landsat ETM 2001 image and Landsat TM 1992 image were classified to the seventeen different land uses.(Table 1and Table 2).

4.3. Accuracy Assessment

Classifications derived from remotely sensed images are subject to error and uncertainty. By selecting random and field sampled ground truth data 100 data points were collected and were utilized in the analyses. Overall Kappa statistics for our analyses of Landsat TM 1992 is 0.84 and the over all classification accuracy is 86.00%. And Overall Kappa statistics for our analyses of Landsat ETM 2001 is 0.92 and the over all classification accuracy is 93.00%.

4.4. Change detection

Remote sensing techniques offer benefits in the field of land use/ land cover mapping and their change analysis. One of the major advantages of remote sensing systems is their capability for repetitive coverage, which is necessary for change detection studies at global and regional scales. Detection of changes in the land use/ land cover involves use of at least two period data sets (Jenson, 1986). Land use/ land cover change is critically linked to natural and human influences on environment.

Using Post-classification change detection method did the change detection of Dal Lake catchment. The land use/ land cover maps prepared from two data sets Landsat ETM (2001) and Landsat TM (1992) were used for change detection. The methodology adopted is shown in fig. 5.

5.Hydrologic Modeling for Watershed Assessment:

Planning and assessment in land and water resource management are evolving from simple, local-scale problems toward complex, spatially explicit regional ones. These problems have to be addressed with distributed models that can compute runoff and erosion at different spatial and temporal scales.

S No.	Class Name	Area (km^2)	% Area
1	Agriculture	19.85	5.93
2	Orchards	16.51	4.93
3	Plantation	35.21	10.52
4	Mixed Forests	67.83	20.26
5	Evergreen Forests	11.63	3.47
6	Degraded Forests	39.34	11.75
7	Built up	5.65	1.68
8	Meadows	19.11	5.7
9	Lake vegetation	19.53	5.83
10	Pastures	3017	9.01
11	River boulders	7.92	2.36
12	Clouds	0.71	0.21
13	Shadow	22.73	6.79
14	Bare Rock	18.71	5.59
15	Fallow	6.46	1.93
16	Barren	1.36	0.4
17	Open water	12.59	3.76

Table 1. Land use/Land cover classes from Landsat TM 1992

S No.	Class Name	Area (km^2)	% Area
1	Agriculture	11.84	3.54
2	Orchards	15.93	4.75
3	Plantation	31.94	9.54
4	Mixed Forests	68.36	20.42
5	Evergreen Forests	15.98	4.77
6	Degraded Forests	33.87	10.12
7	Built up	20.8	6.21
8	Meadows	8.75	2.61
9	Lake vegetation	7.25	2.16
10	Pastures	36.43	10.88
11	River boulders	5.49	1.64
12	Clouds	1.87	0.55
13	Shadow	27.5	8.21
14	Bare Rock	22.84	6.82
15	Fallow	5.86	1.75
16	Barren	5.81	1.73
17	Open water	14.16	4.23

Table 2 . Land use/Land cover classes from Landsat ETM 2001

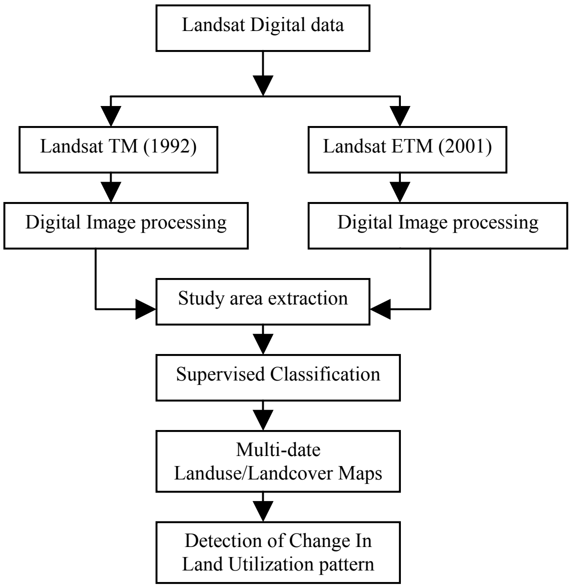


Fig.5. Methodology adopted

The extensive data requirements and the difficult task of building input parameter files, however, have long been an obstacle to the timely and cost-effective use of such complex models by resource managers. The USDA-ARS Southwest Watershed Research Center, in cooperation with the U.S. EPA Landscape Ecology Branch, has developed a Automated Geospatial Watershed Analyses (AGWA) tool to facilitate this process. AGWA provides the framework within which spatially distributed data are collected and used to prepare model input files and evaluate model results.
Spatially distributed models of watershed hydrological processes have been developed to incorporate the spatial patterns of terrain, soils, and vegetation as estimated with the use of remote sensing and geographical information system.

Watershed modeling techniques are useful tools for investigating interactions among the various watershed components and hydrologic response (defined here as rainfall-runoff and erosion relationships). Physically-based models, such as the KINEmatic Runoff and EROSion model (KINEROS) are designed to simulate the physical processes governing runoff and erosion (and subsequent sediment yield) on a watershed. This model can be useful for understanding and interpreting the various interactions among spatial characteristics insofar as the model is adequately representing those processes.

5.1 Modeling sub watershed of Dal lake catchment:

AGWA (a new extention added in Arec view 3.2 GIS Software) is used as preprocessor to the KINEROS 2 Model. The DEM of the study area was used to automatically delinate a user defined watershed boundary. After that the CSA was put 154 ha, and the entire watershed was divided into 57 planes and 23 channels. Then sub watersheds was overlayed with the land use/ land cover and soillayer to derive the HRUs (Hydrological response units), which were automatically derived using the GIS interface.

The second last step was to write precipitation file. The design storm (Pre defined return period) of ten years frequency, 1 hour duration and 2.04 depth was given. And at last Hydrological Model (KINEROS2) was run to import the result in AGWA.

6. Results and discussion:

6.1 Analysis of DEM:

DEM provides (Fig.6) a detail topographic picture of the area. In general the Northeastern part of the area shows maximum relief (between 3500-4200m above MSL), while the Western part shows the low relief (between 1500-2000m above MSL). In rest of the area the topography is undulating and elevation values range from 2000-3000m above MSL. In general, the regional slope of the area is towards west.

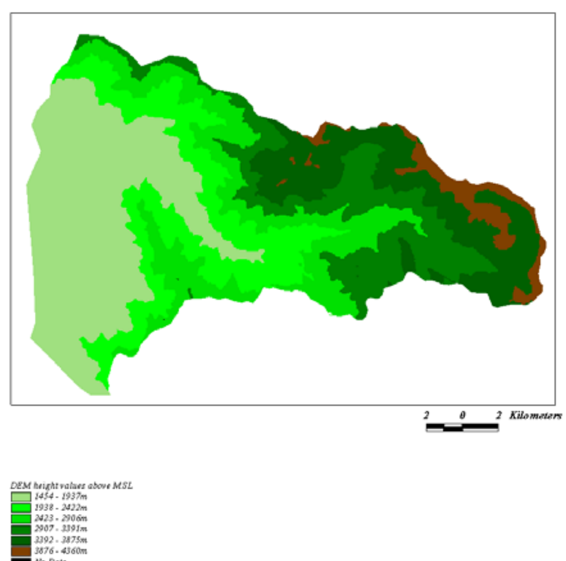


Fig.6. Landform map of study area

6.2. Analysis of Land use/Land cover maps:

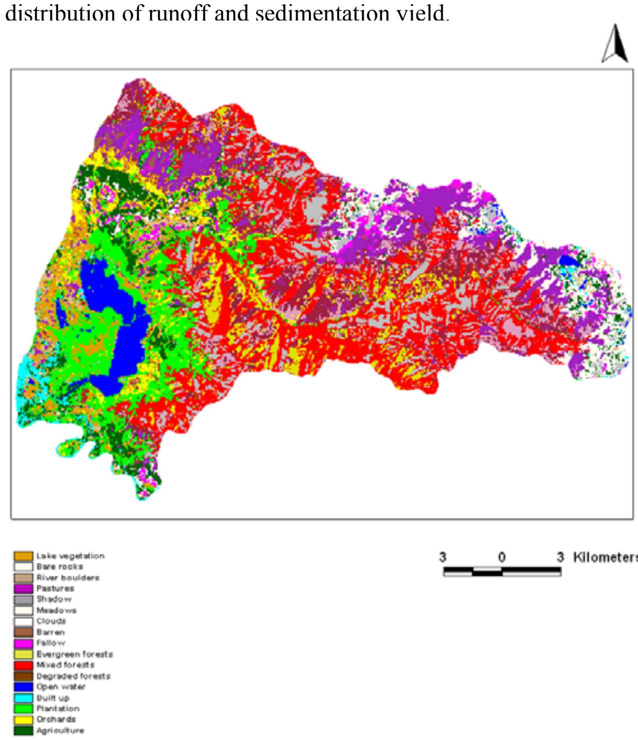
The land use/ land cover maps prepared using the methodology described above have been shown in Figure7 (Landsat TM data of 1992) and Figure 8 (Landsat ETM data of 2001). The various land use and land cover classes delineated include agriculture, orchards, plantation, mixed forest, evergreen forest, degraded forest, built up, meadows, lake vegetation, pasture, river boulders, clouds, shadow, bare rock, fallow, barren and Open water. The spatial coverage of each class may be visualized on both maps. The area of each class for Landsat TM (year 1992) and Landsat ETM (year 2001) data have been shown in Table 1 and Table 2 respectively. The classes dominating in Landsat 1992 are mixed forest (20.26 % area), degraded forest (11.75 % area), plantation (10.52 % area) and pasture (9.01 % area). Agriculture and built up covers 5.93 % area and 1.68 % area respectively. In Landsat 2001 the dominating classes are mixed forest (20.42 % area), pasture (10.18 % area), degraded forest (10.12 % area) and plantation (9.54 % area). Built up and agriculture covers 6.21 % area and 3.53 % area.

6.3. Change Detection:

The land use/ land cover maps are shown in fig.7 (Landsat TM data of 1992) and fig.8 (Landsat ETM data of 2001). The various land use and land cover classes delineated include agriculture, orchards, plantation, mixed forest, evergreen forest, degraded forest, built up, meadows, lake vegetation, pasture, river boulders, clouds, shadow, bare rock, fallow, barren and water. The spatial coverage of each class may be visualized on both maps. The area of each class for Landsat TM (year 1992) and Landsat (year 2001) data has been compiled in Table 3. Table 3 also shows the change pattern in the land use/land cover from year 1992 to 2001 for the Dal Lake catchment. From Landsat ETM land use/ land cover map of year 2001, it may be seen that built up area constitutes 6.21% of total area, while the agriculture, orchard and plantation covers 3.53%, 4.75% and 9.54% area respectively. In year 1992, the built up area obtained from digital image processing techniques has been 1.68% of the total area. The agriculture, orchard and plantation covers 5.93%, 4.93% and 10.52% area respectively. The lake vegetation land constitutes 5.83% in year 2000 while it was 2.16% in 1992.

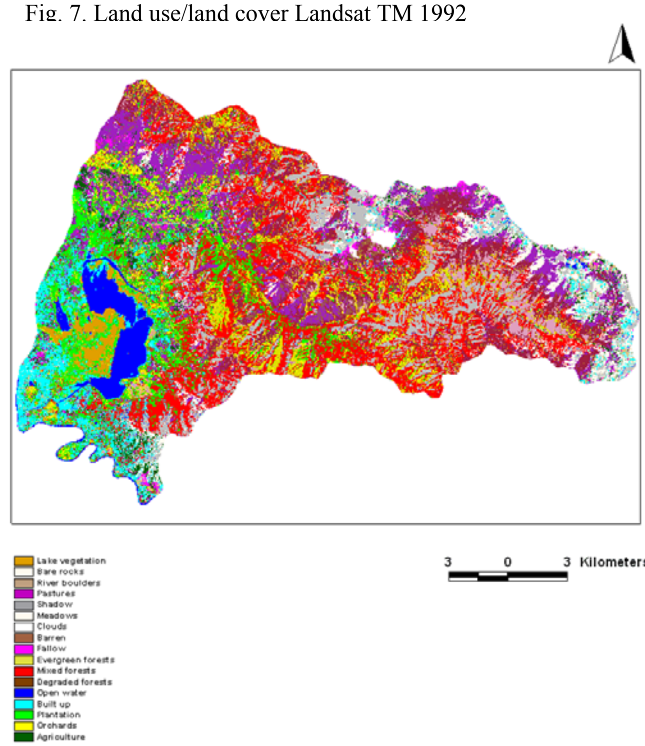
6.4. Model simulations:

KINEROS2 was run on Landsat TM 1992 land use/land cover. The watershed was discretized with a contributing source area of 154 ha, producing 57 sub-watershed elements fig. 9. The same simulation was performed on Landsat ETM 2001 land use/land cover. It is important to note that the model was not calibrated, and in our following analysis of the results we have focused on the relative magnitude and spatial distribution of runoff and sedimentation yield.



Land use/land cover Map of Dal Lake Catchment

Fig. 7. Land use/land cover Landsat TM 1992



Land use/land cover Map of Dal Lake Catchment

Fig. 8. Land use/land cover Landsat ETM 2001

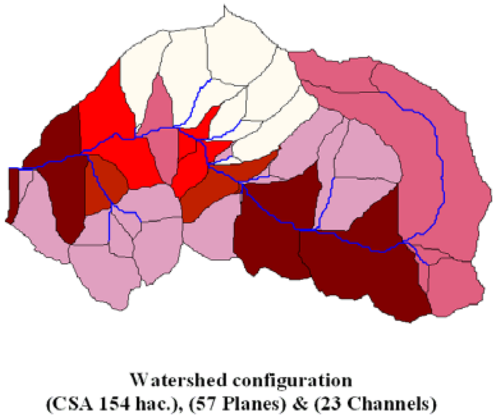


Fig. 9 Watershed configuration

Surface runoff, peak sediment Yield and total sediment yield were simulated using the KINEROS2 model within AGWA. The results from the simulation (Figs. 10, 11, 12, 13, 14, and 15) are

- 0.3 (mm) – 0.27(mm) min. increase in runoff in planes and channels respectively from 1992-2001.
- 04(mm) max. increase in runoff in both planes and channels from 1992-2001.
- 2500(t/ha)- 3000(t/ha) average increase in sediment yield in planes and channels respectively from 1992-2001.
- 400(kg)-5000(kg) average increase in peak sediment yield in planes and channels respectively from 1992-2001.

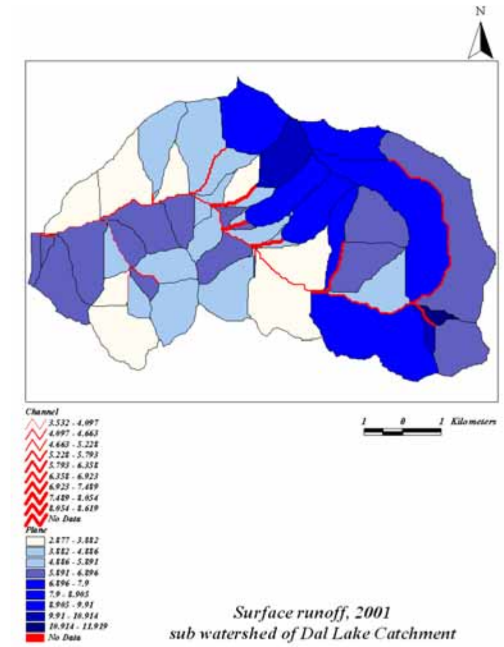


Fig. 11. Surface runoff from land use/land cover 2001

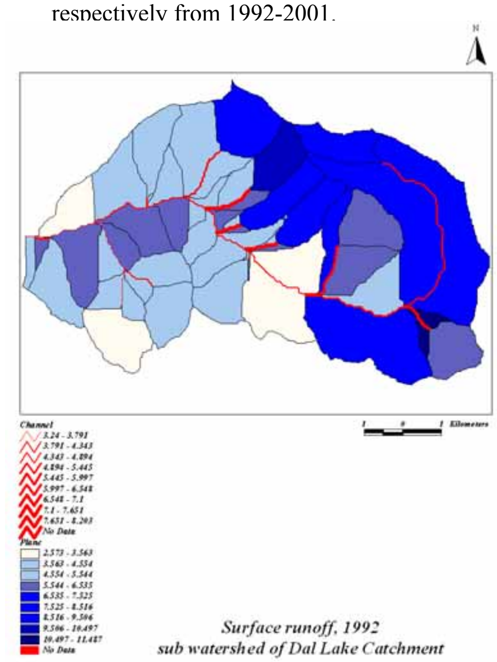


Fig. 10. Surface runoff from land use/land cover 1992

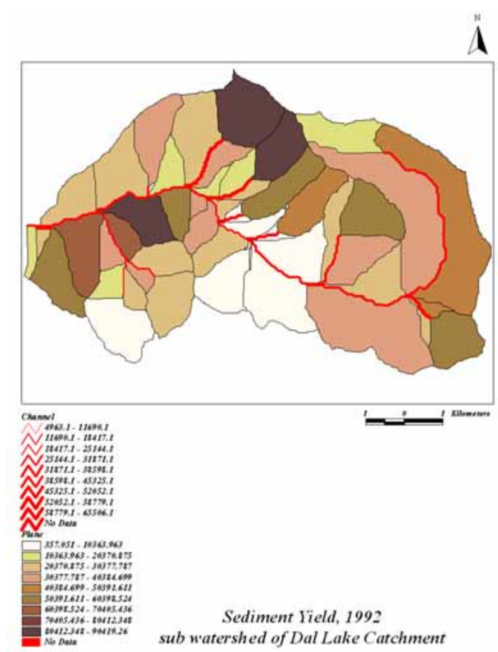


Fig. 12. Sediment yield from land use/land cover 1992

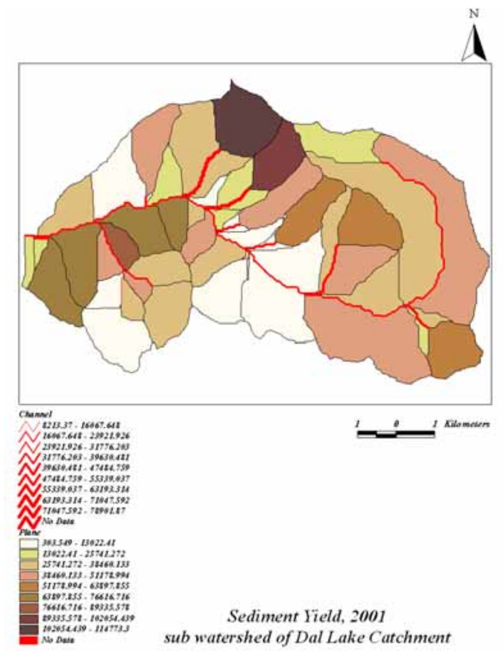


Fig. 13. Sediment yield from land use/land cover 2001

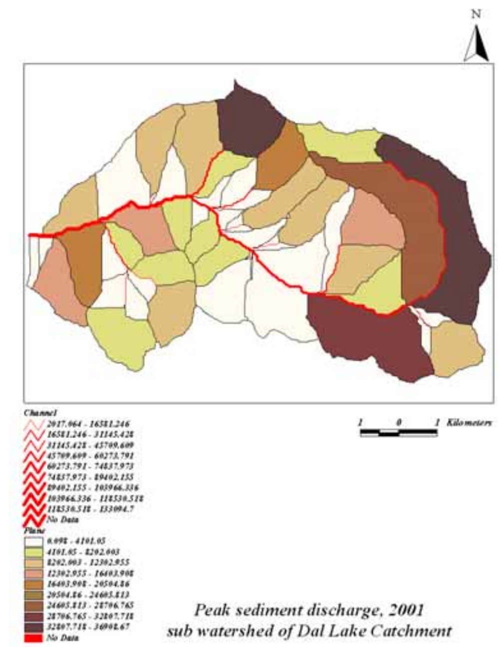


Fig. 15. Peak Sediment discharge from land use/land cover 2001

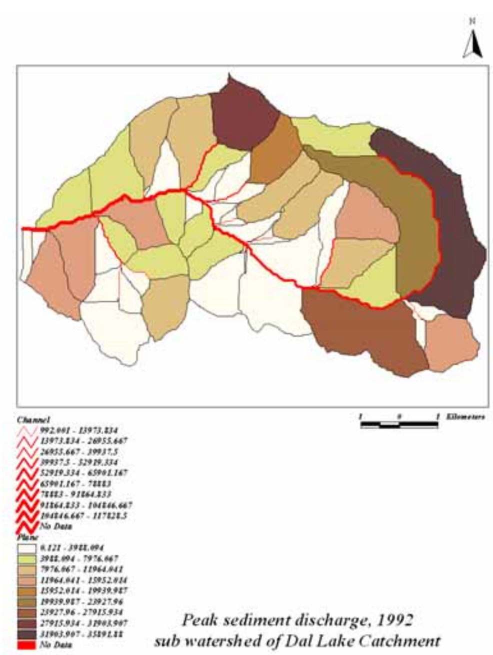


Fig. 14. Peak Sediment discharge from land use/land cover 1992

Conclusions:

Remote sensing now a days has become a modern tool for mapping of land use/ land cover for micro, meso and macro level planning. Remote sensing systems have the capability for repetitive coverage, which is required for change detection studies. For ensuring planned development and monitoring the land utilization pattern, preparation of land use/ land cover map is necessary. The land use land cover maps of Dal lake catchment were prepared using landsat TM 1992 and Landsat ETM 2001. The various Land use/Land cover classes delineated include agriculture, orchards, plantation, evergreen forests, mixed forests, degraded forests, built up, meadows, lake vegetation, pastures, river boulders, clouds, shadow, bare rock , fallow, barren and water. The important thing that was noticed is that the vegetation class weather it is any type of forest or plantation is dominating. About 40% of the area is covered by vegetation. One of the main advantage of making 2 date land use / land cover map of the study area is to detect change in land use/ land cover. The changes in land use/ land cover due to natural and human activities was observed. It was noticed that within 9 years (1992-2001) the built up has increased (+4%) and more importantly the meadows are reduced in area (-3.09%) Rest of classes has a change of +- 1%. Like land use / land cover

DEM is also one of the valuable information of any area. DEM helps to determine slope, steepness, slope length, flow direction, areas, boundaries and out let of watersheds. DEM of the study area provides a detail topographic picture of the area. Maximum relief >3500 meter in North eastern part , minimum <2000 meter in West and in East an elevation range of 2000-3000 meter. The land cover maps derived by remote sensing are the basis of hydrologic response units for modeling units. This study has looked into the possibility of combining remotely-sensed with ancillary data, in order to study the potential relationship between LULC changes and land degradation in the Dal Lake catchment. This was achieved using two largely recognized indicators of degradation: surface runoff and soil erosion. In order to compute the sediment yield and runoff for a sub watershed of Dal catchment a physically-based runoff-erosion model called KINEROS2 was used. The computations showed that the model can be used to simulate the runoff due to continuous rainfall events. The results, produced using a high rainfall event, have identified areas where runoff and erosion figures are increasing as well as areas where these figures are less now than they were in the 1992s. It is hoped that these results would facilitate the prioritization of the micro-watershed in the catchment so that corrective and mitigation measures are taken to arrest the land degradation in the watershed. Changes in landscape pattern and their eco-hydrological effects have been regarded as a hotspot and leading issue in scientific research in many disciplines such as ecology, hydrology, and geography. Changes in landscape pattern had a major impact on material and energy movement by changing a series of eco-hydrological processes, such as runoff, water quality, and soil erosion. It is necessary to discuss in depth landscape pattern changes and their eco-hydrological effects, which will be helpful to integrated management and exploitation and of positive significance to the research focusing on regional sustainable development and global environmental changes.

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. Area of Each Class for Landsat TM (1992) and Landsat ETM (2001)							
S. No.	**Land Use/ Land**	**Area in 2001**		**Area in 1992**		**Change(km^2)**	**Change(%)**
		Area (Km^2)	**% Area**	**Area (Km^2)**	**% Area**		
1	Agriculture	11.84	3.53	19.85	5.93	-8.01	-0.4
2	Orchards	15.93	4.75	16.51	4.93	-0.58	-0.18
3	Plantation	31.94	9.54	35.21	10.52	-3.27	-0.98
4	Mixed Forests	68.36	20.42	67.83	20.26	0.53	0.16
5	Evergreen Forests	15.98	4.77	11.63	3.47	4.35	1.3
6	Degraded Forests	33.87	10.12	39.34	11.75	-5.47	-1.63
7	built up	20.8	6.21	5.65	1.68	14.43	4.53
8	Meadows	8.75	2.61	19.11	5.7	-10.36	-3.09
9	Lake vegetation	7.25	2.16	19.53	5.83	-12.28	-3.67
10	Pastures	36.43	10.88	30.17	9.01	6.26	1.87
11	River boulders	5.49	1.64	7.92	2.36	-2.43	-0.72
12	Clouds	1.87	0.55	0.71	0.21	1.16	0.34
13	Shadow	27.5	8.21	22.73	6.79	4.77	1.42
14	Bare Rock	22.84	6.82	18.71	5.59	4.13	1.23
15	Fallow	5.86	1.75	6.46	1.93	-10.96	-0.18
16	Barren	5.81	1.73	1.36	0.4	4.45	1.33
17	Open water	14.16	4.23	12.59	3.76	1.57	0.47

Table 3 Area of Each Class for Landsat TM (1992) and Landsat ETM (2001)