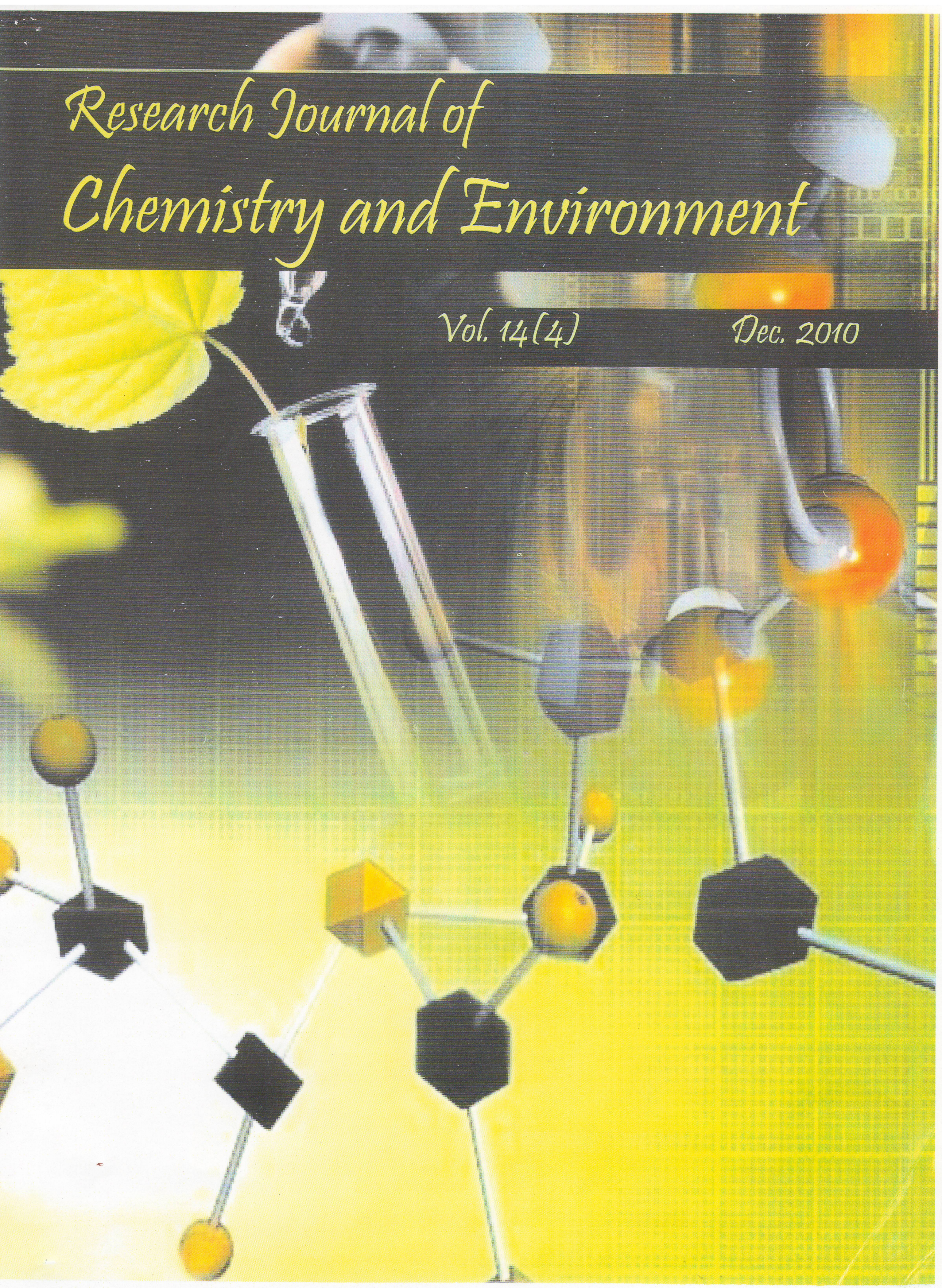

Research Journal of
Chemistry and Environment
Vol. 14(4)
Dec. 2010

Review Paper:

Applications of GIS in Wetland Management: An Overview

Premalatha M., Abbasi Tasneem and Abbasi S. A.*
Centre for Pollution Control & Energy Technology, Pondicherry University, Chinakalapet, Puducherry 605 014, INDIA
*prof.s.a.abbasi@gmail.com

Abstract

GIS is becoming an increasingly useful tool in carrying out environmental management. In conjunction with remote sensing, GIS helps in (i) bringing forth the hidden patterns in a dataset (ii) perform queries (iii) store, edit and retrieve data in the form of maps, tables or graphs and (iv) prepare exceedingly 'expressive' maps to facilitate survey, spatial modeling, analysis and decision-making. This paper aims to take stock of the GIS capabilities which are particularly relevant to wetland management.

Keywords: Wetland management, GIS, Applications.

Introduction

The importance of water and wetlands in not only our well-being but our very survival can hardly be overemphasized. But both have been seriously degraded and are in urgent need for restoration. GIS (geographical information systems), can play a major role in facilitating quick assessment of water pollution and wetland degradation. It also enables us to se and spatially model wetlands in the context of population clusters, transportation networks, developmental activities and other ecosystems etc. which influence the wetlands. These assessments form the basis for developing strategies for wetland restoration appropriate in the give context. GIS enables all this to be accomplished with much more speed, accuracy and precision – and at much lesser costs – then is otherwise possible. Some of the capabilities of GIS which are utilized in environmental management are briefly described below.

Delineation of land use and land cover: Land use and land cover of a watershed / river basin can affect the quality of surface / ground water directly. For instance, if the presence of land cover in the form of forests dominates in a catchment, it would reduce the possibility of soil erosion. In case agriculture happens to be the most dominant land use, it would contribute agricultural inputs in the form of fertilizers and pesticides and soil sediments to the water resources as run-off or through infiltration.

Overlay analysis: This feature of GIS can be highly useful in preparing new maps showing spatial distribution as well as interaction of parameters by overlaying selected maps. For example a map of soil erosion index can be prepared by overlaying individual maps of digital elevation model (or three-dimensional elevation which gives Information on the slope of the terrain), soil type and land cover (which provide clue to the potential of runoff. The process is illustrated in figure 1.

Buffering: This feature can be used for delineating the vulnerable areas or zones of high risk, or hot spots in a region. It can also help in identifying an emerging new region around a known feature. For instance if it is known that regions which are within 2 km of a reservoir would be flooded, these regions can be delineated using the buffer tool (Figure 2).

Aggregation or redistricting: This feature is useful in the mapping and performing of what if analysis. Say, if there are three classes of vegetation which are delineated – jungle, scrub jungle and open scrub. The user wishes to club these into two groups – jungle and scrubs. The user can do this easily by clubbing the scrub jungles and open scrub and labeling this new group scrub by using the feature called redistricting. (Figure 3)

Network analysis: This feature enables the user to find out the shortest path between two locations, say the distance between one sampling site and the other. The pattern and the distance a stream flows in a drainage basin can also be calculated by using network analysis.

View shed mapping: A three dimensional elevation model (DEM) of a landscape or the region of interest enables viewing the terrain in different perspectives (Figure 4). The DEM can also provide vital information on the terrain slope which can be useful in arriving at soil erosion index.

Thematic maps: Thematic maps represent numerical data in relation to the concerned area. The variability can be seen as it changes spatially. Aside being more informative, thematic maps also have a better visual appeal compared to the tabulated data or conventional graphs (Figure 5).

Spatial analysis: The spatial data can be interpolated or extrapolated using several models such as nearest neighborhood and krigging. The spatial data can also be represented as line contours (elevation contours as lines) or as regions (elevation contours as regions), or as grid (a map representing various data values as continuous gradient of colors). Further, the grid can be represented as a DEM (3 D elevation model). These forms of representations are illustrated in figure 6.

Applications of GIS in Wetland Management

Present below are illustrative examples of the myriad of investigations and applications carried out across the world on different aspects of wetland management using GIS. These case studies indicate the versatility as well as the range of applicability of GIS and remote sensing.

GIS in hydrological studies

Monitoring small dams in semi-arid regions using remote sensing and GIS: The analysis of data from high spatial resolution satellite-mounted infrared sensors has the potential to monitor the water stored by small dams in semi-arid areas. Finch[14] has described a simple method of analysis and particular attention is given to selecting an appropriate threshold level to discriminate water from non-water land cover. The use of GIS allows further discrimination of the areas of water from other areas such as deep shadow, which have been classified incorrectly and facilitates the automatic calculation of dam capacities. The success of the technique was demonstrated on data from two regions in Botswana.

Assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS: The investigation of basins for planning soil conservation requires a selective approach to identify smaller hydrological units which would be suitable for more efficient and targeted conservation management programs. One criterion, generally used to determine the vulnerability of catchments to erosion, is the sediment yield of a basin. In India, sediment yield data are generally not collected for smaller sub-catchments and it becomes difficult to identify the most vulnerable areas for erosion that can be treated on a priority basis. An index-based approach, based on the surface factors mainly responsible for soil erosion, is suggested in a study by Jain and Goel[17]. These factors include soil type, vegetation, slope and various catchment properties such as drainage density, form factor etc.

The method adopted by Jain and Goel[17] has been illustrated with a case study of sub-catchments immediately upstream of the Ukai Reservoir located on them River Tapi in Gujarat State, India. The area is divided into 16 watersheds and different soil, vegetation, topography and morphology-related parameters are estimated separately for each watershed. Satellite data are used to evaluate the soil and vegetation indices while a GIS system is used to evaluate the topography and morphology-related indices. The integrated effect of all the parameters is evaluated to find different areas vulnerable to soil erosion. Two watersheds were identified as being most susceptible to soil erosion. Based on the integrated index, a priority rating of the watersheds for soil conservation planning is recommended.

Geographic information systems (GIS) - based spatially distributed models for runoff routing: GIS offers many new opportunities for hydrological modeling. They can be used to form spatially distributed models of watershed. Hrissanthour et al[15] have used a rainfall-runoff sub-model for the computation of the surface water volume inflowing into the Kastoria lake from the main streams of the sub-basins located around the Lake. A quasi-three-dimensional simulation model of the Kastoria basin aquifer was also realized in order to estimate the groundwater contribution to the volumetric budget of the lake and the whole basin as well. For the computation of sediment load inflowing into the lake from the main streams of the sub-basins, the rainfall-runoff sub-model was combined with a soil erosion sub-model and a sediment transport sub-model for streams. A GIS was developed in the hydrologic basin with all data needed for parameter identification and model application. The data base was enriched by a series of on site measurements of water discharge made in all main streams for one whole hydrologic year. By means of the resulting mathematical sediment model, those sub-basins, which deliver most sediment load to the lake, are identified. On the basis of this identification, a series of control measures, for the reduction of sediment inflowing into the lake, at certain places of the above mentioned sub-basins is proposed.

Schumanna et al[45] have presented an approach: how statistical descriptions of distributed catchment characteristics could be used to consider spatial heterogeneity within conceptual models. Three semi-distributed modules are presented. The three components are combined to a hydrological model including feedback components between surface flow and infiltration and between subsurface return flow and surface flow in saturated areas. The model was set up to use spatially distributed information about catchment characteristics for the estimation of its parameters. By a direct estimation of some model parameters from a GIS-based analysis of the catchment characteristics, the number of calibration parameters can be reduced. In the second part it is shown how the application of this model to different catchments within a region can benefit from boundary conditions for optimization, which are derived from a GIS considering the differences of catchment characteristics.

Olivera and Maidment[33] have proposed a method for routing spatially distributed excess precipitation over a watershed to produce runoff at its outlet. The land surface is represented by a (raster) digital elevation model from which the stream network is derived. A routing response function is defined for each digital elevation model cell so that water movement from cell to cell can be convolved to give a response function along a flow path and responses from all cells can be summed to give the outlet hydrograph.

GIS-based modeling of streamflow, baseflow and runoff: Models which can predict total streamflow (TSF), baseflow (TBF) and storm runoff (TRO) are needed for water resource planning and management. TBF was considered a surrogate of groundwater recharge for basins. Regression models for predicting basin-wide TSF, TBF, and TRO were developed under three scenarios that varied in regression variables used for model development. The variables representing basin geomorphological, geological, soil and climatic characteristics, were estimated using GIS. All regression models for TSF, TBF, and TRO had R^2 values >0.94 and functional within reasonable prediction errors. The two best TSF models developed under scenarios 1 and 2 had similar absolute prediction errors. The same was true for the two best TBF models. Therefore, any one of the two best TSF and TBF models could be used for respective flow prediction depending on variable availability.

Use of GIS to characterize aquifer-river interaction processes: The interconnections between groundwater and river systems remain poorly understood in many catchments throughout the world and yet they are fundamental in effectively managing the quantity and quality of water resources. Many of the techniques traditionally employed by hydro geologists and hydrologists rely on characterizing the groundwater flow systems, topography, geology/aquifer systems, climate and/or the rainfall-runoff processes within a river basin. These studies can provide useful process characterizations that are fundamental to developing a physical understanding of hydrological processes within a specified region. However, in many instances the findings are descriptive and the results are difficult to up-scale to the larger sub-catchment/catchment scale at which water is managed and allocated. Moreover, they may have significant time and cost requirements. An alternative approach is to collate a range of hydrometric data, which for many catchments may already be available and to analyze patterns and infer processes from the data without being overly concerned about the details of the physical processes driving the system taking a top-down approach.

Using this approach the river reaches in the semi-arid Namoi River catchment in Australia were characterized by Ivkovic[16] according to three levels of information; namely: (1) presence of aquifer-river hydraulic connection; (2) dominant direction of flux; and (3) the potential for groundwater extraction to impact on river flows. The methods used to characterize the river reaches included an analysis of: (1) groundwater and river channel base elevations using a GIS/database; (2) stream hydrograph data; (3) flow duration data; (4) vertical aquifer connectivity at nested piezometer sites; and (5) paired river and groundwater hydrographs. The data patterns seen in the stream gauging station derived data for gaining, losing and variably gaining-losing river reaches were described together with the general processes that operate in these systems. Subsequently, a map was prepared for the Namoi River catchment river reaches indicating aquifer-river connectivity and dominant direction of flux (Figure 7). The potential for groundwater extraction was found to cause a significant impact on the connected aquifer-river systems.

Use of GIS to study the impact of land-cover/land-use on wetlands and associated ecosystems: Every wetland has its own clearly defined 'catchment' or 'basin'. All the water falling over that catchment flows in the direction of the lowest point in the wetland. If the catchment is such that it does not cause sediments and other pollutants to join the run-off, there will be little or no adverse impacts of the catchment on the wetland. Conversely if the catchment is degraded or polluted, it will contaminate the run-off and eventually harm the wetland. To protect a wetland it is essential to protect its catchment. Otherwise no amount of dredging, desalting, or de-weeding can keep a wetland 'clean' for long.

Influence of surface mining and reclamation: Surface mining and reclamation strongly influence land cover land use change (LCLUC). Accurate quantification of the extent of mining activities is important for assessing how this LCLUC affects ecosystem services such as aesthetics, biodiversity and mitigation of flooding.

Townsend et al[51] used Landsat imagery from 1976, 1987, 1999 and 2006 to map the extent of surface mines and mine reclamation for eight large watersheds in West Virginia, Maryland and Pennsylvania (USA). They employed standard image processing techniques (Figure 8) in conjunction with a temporal decision tree and GIS maps of mine permits and wetlands. These were used to map active and reclaimed mines and track changes through time. The active surface mine extent was found to be highest in 1976, prior to implementation of the Surface Mine Control and Reclamation Act in 1977, with 1.76% of the study area in active mines, declining to 0.44% in 2006. The most extensively mined watershed, Georges Creek in Maryland, had 5.45% active mines in 1976, declining to 1.83% in 2006. The area of reclaimed mines increased from 1.35% to 4.99% from 1976 to 2006 and from 4.71% to 15.42% in Georges Creek. Land cover conversion to mines and then reclaimed mines after 1976 was almost exclusively from forest. Accuracy levels for mined and reclaimed cover was above 85% for all time periods and was generally above 80% for mapping active and reclaimed mines separately, especially for the later time periods in which assessment data of good accuracy were available.

The study revealed that the mapped patterns of LCLUC are likely to significantly affect watershed hydrology, as mined and reclaimed areas have lower infiltration capacity and thus cause more rapid runoff than unmined forest watersheds. This would lead to greater potential for extreme flooding during heavy rainfall events.

Since long-term ecological data were not available, a simple method was developed to estimate the accumulated ecological effect of highway networks on wetlands. First, the changes of wetlands areas within the road-effect zone from 1980 to 2005 using GIS were analyzed. Secondly, the changes of the ecological functions of wetlands caused by road networks were analyzed based on correlations of ecological function to wetland area and water depth. Finally, the changes of ecological function of wetland affected by planned highway networks from 2010 to 2020 were fore- casted. The negative ecological effect of highway networks on wetlands was obvious and the effect increased with the increased density of highway networks. The ecological function index in 2005 was 86% of that in 1980. If the current trend continues, the ecological function indexes in 2010 and 2020 will be 80% and 59% of that in 1980 respectively. Therefore, the negative ecological effect of highway networks on wetlands will be more severe in the coming years and measures should be taken to protect and restore the wetland ecosystems. This study gives some guidelines on alleviating negative effects of highway networks on wetland ecosystems and provides scientific support for highway network planning.

Linkage between river water quality and landscape metrics: The use of GIS in assessing the impact of catchment on river water quality is illustrated with a case study of Amiri and Nakane[2]. They used secondary database, remote sensing, GIS and multivariate analysis tools to develop Multiple Linear Regression (MLR) models that could predict level of water quality variables using compositional and spatial attributes of land cover in the river basins.

The study encompassed 21 river basins with 32 000 km^2 area located in the Chugoku district in West Japan. Biological Oxygen Demand (BOD), pH, Dissolved Oxygen (DO), Suspended Solid (SS), Total Nitrogen (TN), and Total Phosphorus (TP) were considered as water quality variables of the stream. Satellite data were used to generate the land cover map of the study area. MLR models were developed using the compositional (%) and spatial attributes (landscape metrics) of the land cover at watershed and class levels for representing the land cover-stream water quality linkage.

The results of the MLR modeling using the land cover data revealed that 92%, 74% and 62% of the total variations in concentration of DO, pH and TP were explained by changes in the measure of the spatial attributes of the land cover in the study area. The models tested by the authors can help local and regional land managers to understand the relationships between the compositional attribute (%) and the spatial features of the land cover and river water quality. The models can be applied in formulating plans for watershed-level management.

Quantifying bank erosion and its importance in assessing Hg contamination: There are many land areas which might have been contaminated several decades ago but which may contribute to wetland pollution in the present time and in future due to movement of contaminated sediments with run-off. This case study by Rhodes et al[43] addresses such a situation. Bank sediments along a 40 km reach of the South River, downstream of Waynesboro, USA, contain high levels of mercury due to past contamination from the textile manufacturing units. Knowledge of the rate at which contaminated sediment is released to the stream channel through bank erosion can help in implementing restoration programs designed, for example, to minimize its ecological impact and to reduce risk to human health.

Digitized stream channel boundaries based on visual interpretations of geo-referenced aerial imagery from 1937 and 2005 were compared to calculate a minimum estimate of the total area of bank sediment eroded between Waynesboro and Port Republic, Virginia. Estimates of riverbank height were extracted from aerial LIDAR data, allowing areal estimates of bank retreat to be converted to volumes. Nominal annual rates of bank retreat, averaged over the 68-year period, were found to be low, ranging from 3 to 15 cm per year.

Bank erosion occurred at the outside banks of bends through the development of islands, where deposition on confluence bars pushed the main flow into the opposite bank and in small areas along the channel. A minimum estimate of the total volume eroded for the study reach is approximately 161,000 m^3; the corresponding annual mass of mercury that reaches the channel by bank erosion is 109.6 kg/year. This work demonstrates that a careful analysis of aerial imagery and LIDAR data can provide detailed, spatially explicit, estimates of mercury loading from bank erosion, even when rates of riverbank erosion are unusually low.

Assessing factors which influence the spatial distribution of organochlorine pesticides in soils surrounding industrial complexes: GIS can be helpful in assessing the spatial distribution of pollutants in areas surrounding the pollutant's source of origin as also the extent of risk posed by the pollutants. The occurrence and distribution of target organochlorine pesticides (OCPs) in the vicinity of an industrial complex in Tianjin, China, were mapped by Wang et al[52] to identify their spatial variation using GIS. In general, the concentrations of OCPs were higher in soils near the Industrial parks, even some hot spots showed very high OCP contaminations which could cause ecological risk. The relationships between contaminant concentrations and other factors (land use and soil properties) revealed significant correlations between TOC contents and the concentrations of DDTs, α-HCH, and β-HCH.

Except for the effects of the industrial parks, the capacities of biodegradation and dissipation of soils under different land uses were the important factors that affected the HCH distribution but the distribution of DDTs was mainly influenced by the TOC levels. The results of this study provide evidence and data on the long term effects of industrial activities in the environment even after the cessation of operations for a long time.

A new GIS tool for evaluation of nitrate leaching: Underground concentrations of nitrate nitrogen are generally higher then the limits which are safe for drinking. Hence nutrient managers and policy makers need tools that can quickly and qualitatively rank the different practices which introduce nitrate nitrogen to enable selection and implementation of best management practices (BMPs) across a region.

A new tier one GIS N index tool (GIS NIT-1), based on quantitative N mass balance and qualitative rankings, has been developed by Paz et al[39] to assess N management practices in a region. The ne GIS NIT-1 assessment tool was able to simulate N uptake, hydrological characteristics (water leaching), N dynamics and NO_3-N leaching across several sites. The authors suggest that the GIS NIT-1 can be used to quickly identify practices that produce very low to moderate N losses to the environment from those with high and very high N rankings. GIS has also been used to develop a regional modeling framework to estimate the net cost of land-applying manure under possible policy provisions to limit water and air-quality emissions. The modeling framework integrates GIS-based spatial data within an optimization model to capture spatial effects at a sub watershed scale.

A Stream-Wetland-Riparian (SWR) index for assessing condition of aquatic ecosystems in small watersheds: Books et al[4] have developed and tested a protocol for rapidly assessing the conditions of the stream, wetland and riparian components of freshwater aquatic ecosystems. Aspects of hydrology, vegetation, in-stream and wetland characteristics and on-site stressors are measured in the field. The resulting metrics are used to develop an index of overall condition termed as the Stream-wetland -Riparian (SWR) Index (Figure 9).

Values of this index were compared to existing biotic indices and chemical measures and to a Landscape Index created using satellite-based land cover data and a GIS. Comparisons were made at several levels of spatial aggregation and resolution from site to small watershed. The SWR Index and associated Landscape Indices correlated highly with biological indicators of stream condition at the site level and for small contributing areas.

Application of remote sensing and GIS to study the impact long-term changes in land use and land cover: A study covering 45 year span (1960-2005) has been carried out on land use/cover changes in Dhaka Metropolis of Bangladesh using topographic maps and multi-temporal remotely sensed data[12]. The maximum likelihood supervised classification technique was used to extract information from satellite data and post-classification change detection method was employed to detect and monitor land use/cover change. Derived land use/ cover maps were further validated by using high resolution images such as SPOT, IRS, IKONOS and field data. The overall accuracy of land cover change maps, generated from Landsat and IRS-1D data, ranged from 85% to 90%.

The analysis indicated that the urban expansion of Dhaka Metropolis has resulted in considerable reduction of wetlands, cultivated land, vegetation and water bodies. The maps showed that between 1960 and 2005 built-up areas increased approximately by 15,924 ha, while agricultural land decreased by 7,614 ha, vegetation decreased by 2,336 ha, wetland/lowland decreased by 6,385 ha and water bodies decreased by about 864 ha. The amount of urban land increased from 11% (in 1960) to 344% in 2005. The growth of landfill/bare soils category was about 256% in the same period. The study reveals that much of the city's rapid growth in population has been accommodated in informal settlements with little attempt being made to limit the risk of environmental impairments.

In other study using GIS, Devan and Yamaguchi[12] found that as the land use in the watershed shifts from predominantly agricultural to mixed rural and residential lands, a reduction in flow, sediments, and nutrients is detected. Although the projected average daily concentration of phosphorus is reduced by 47%, under the future land-use scenario it will still exceed the daily limit suggested by the US Environmental Protection Agency. Several other aspects of urbanization, including risks of accidents Bhopal gas tragedy need to be addressed with GIS[18-28].

Assessment of wetland fragmentation: The wetlands in the middle and lower reaches of the Tarim River are rich in biodiversity and natural resources in the inland arid region of China. However, these wetlands area has decreased in size during the past several decades. Water quality and biodiversity have declined due to expanded agricultural activities since 1960s. The total area of the wetlands was reduced by 45.8% and the density of the patches increased four times from 1980 to 1990. From 1990 to 2000, though the total area of the wetlands slightly increased the number of the patches also increased three times and the density of the patches doubled (Figure 10). Based on the analyses of transition matrixes, diversity and fragmentation indexes and spatial distribution alternation of the wetlands, the landscape diversity and fragmentation indices increased while wetland dominance index decreased dramatically. Among the wetland types, the areas of the river-channel, reservoir and pond wetlands increased while the areas of the lake and marsh wetlands decreased continuously.

Temporal mapping of deforestation and forest degradation: Deforestation and forest degradation are associated with a series of processes resulting in the conversion of forest area into a mosaic of mature forest fragments, pasture, and degraded habitat. Monitoring of forest landscape spatial structures is necessary to detect degenerative trends in forest conditions. GIS and remote sensing play an important role in the generation of such data to identify degraded and deforested areas as well as potential areas for conservation.

Panta et al[37] analyzed forest degradation and deforestation trends in Chitwan district in Nepal which contains key habitat elements for wildlife in the region. An artificial neural network was used to predict forest canopy density in five classes using Landsat images of the year 2001. Forest canopy density was predicted with 82% overall accuracy. Except riverine forest, forest area of all other forest types was reduced. Terai *Shorea robusta* forest, which has high commercial value, showed a loss of 23% between 1976 and 1989. An overall loss of 15% forest cover was seen between the years 1976 and 2001. The authors found that deforestation and forest degradation disproportionately reduced the sizes of the different forest types, a finding that has important management implications.

Application of GIS in fisheries science: Introduction of GIS to fisheries science has been relatively recent compared to other disciplines. This is due, in part, to the inherent complexity of the environment where fishes' life cycles take place and to the complexity of fisheries dynamics as well. GIS have been developed mainly for terrestrial landscapes and many of their algorithms are not suitable for marine ecosystems. The principal challenges in the implementation of GIS to fisheries research have to do with the three dimensional space where fish live, temporal variability and fuzziness of the data sets. Yet there are increasing number of studies in fisheries science which incorporate GIS in research.

Marrsa et al[30] have done a 4-month pilot study on micro-scale mapping of Nehrops trawler effort in the Clyde Sea area, west Scotland, using global positioning system (GPS)-based position data loggers. The position data loggers have provided unbiased, accurate fishing effort data at a scale hitherto unrecorded. The trawl location data were combined with the daily landings obtained from a complementary confidential logbook scheme using GIS to produce maps of fishing effort, cumulative landings and landings per unit effort. GIS can also be used in integrating traditional and scientific knowledge in fisheries management.

An integration of local harvesters' knowledge of attitudes and practices toward the resources they harvest with scientific information is essential to natural resources management. However, the past attempts have, in most cases, not been effective because of a failure to use all available sources of information and knowledge.

A multi-layer GIS database integrating local fishers' and scientific knowledge was developed with ArcGIS and ArcView tools to integrate and translate information into an accessible and interpretable format. The geo-spatial database interface allowed the selection of specific data characteristics by target species, harvest areas, fishers' communities, fishing gear, catch-per-unit of effort (CPUE) and monthly landings. The observed fishing spatial dynamics presented among the fishers' communities showed that in most cases, artisanal fishermen tend to concentrate in shallow estuarine waters surrounding their villages.

Assessing changes in the water quality as indicated by submerged macrophytes using GIS: Use of GIS has been demonstrated in mapping and storing information on submerged vegetation allowing easy interrogation, updating and plotting of spatial information at various scales and providing a reference for future comparisons. This is illustrated by the long-term studies of Lehmann and Lachavanne[29] who studied the distribution of submerged macrophytes along 20 km of lake shore (Lake Geneva, Switzerland) between the years 1972, 1984 and 1995. Lake Geneva underwent rapid eutrophication until 1980, followed by reversal that is still in progress. *Potamogeton, pectinatus, P. perfoliatus, P. lucens and Elodea Canadensis* showed no significant changes in their distribution, with the two former species dominant throughout.

Chara sp. and to a lesser degree *Myriophyllum spicatum,* decreased in abundance between 1972 and 1984 but had increased again by 1995. The abundance of *P. pusillus* increased regularly while *Zannichellia palustris* and *P. crispus* almost disappeared from the study area. *Elodea nuttallii* was observed for the first time in Lake Geneva in 1995.

Management of wildlife linked to wetland habitats

Change detection analysis in bird habitat by the integration of remote sensing and GIS: Wetlands provide habitats to various kinds of animals and plants, some of which are endemic and perform vital ecosystem services, including carbon sequestration, water quality protection and flood mitigation. Unfortunately wetlands are destroyed by human-induced drying out of marshes, unplanned urbanization, agriculture and water pollution. Dogru et al[13] have determined the dimensions of the continuing human-induced ecological disaster at the Izmir bird sanctuary, Turkey. For this purpose, integration and classification techniques were used by them to measure the changes in the bird sanctuary by using Landsat data acquired in 2000, 2003 and 2006. The results show that urbanization has seriously affected the study area during the 6-year period. The urban areas have been expanded from 1626.66 ha to 3439.35 ha, and the wetland areas have been reduced from 701.55 ha to 585.63 ha. A considerable amount of area loss has occurred to the agricultural lands.

Population size, distribution and habitat selection of the white-tailed eagle *Haliaeetus albicilla*: From 2003-2006, GIS-assisted research on the breeding distribution of the white-tailed eagle (*Haliaeetus albicilla*) was conducted in Croatia in order to assess the size of the national population[42]. In 125 locations, clear signs of breeding activity were found. An additional 10 presumably active territories were detected but it was not possible to locate the exact position of the nests and confirm the breeding (Figure 11). Based on this, it was concluded that not less than 135 breeding pairs exist in Croatia. Analysis of the characteristics of 138 nest positions as well as preferences/avoidance of specific structural features showed that white-tailed eagles prefer to build their nests on pedunculate oaks, narrow-leafed ash and white poplars with the greatest preference for mature trees with a diameter above 92.5 cm. The minimal distance between two active pairs was 348 meters.

More than 50% of the population was found to breed less than two km from a large water area and 95% of the population less than four km. More than 95% of the population bred at altitudes lower than 140 m above sea level and further than one km away from the nearest human settlement, regardless of the availability of forests. According to several parameters (distance to a large water area, elevation, forest presence, distance to the nearest settlement, distance to highways and railways) GIS helped to determine potential white-tailed eagle breeding areas.

Shorebird distribution models: Coastal landscapes with extensive intertidal mudflats provide non-breeding habitat for Arctic shorebirds. Few attempts have been made to develop and test landscape-level models predicting the intertidal distribution of these birds. Snowy Owls (*Nyctea scandiaca)* influenced Dunlin distribution and thus model transferability. After accounting for their presence, models displayed good to excellent discrimination, i.e. prediction of the instantaneous and cumulative (over low tide period) probability of mudflat use by Dunlin, in fore- and backcasting applications. The models were amenable to GIS application and revealed the amount of use per hectare of the intertidal zone. The models can be used to determine and visualise relative and absolute suitability of intertidal areas.

Mercury bioaccumulation in riverine turtle *Podocnemis* erythrocephala: A number of environmental factors influence the dynamics of mercury in aquatic ecosystems, yet few studies have examined these factors for turtles. The red-headed river turtle *(Podocnemis erythrocephala)* is easy to capture making it the turtle species that is consumed most often by people of the region. In a study by Schneider et al[47], environmental factors and turtle size were investigated to determine their influence on the Hg concentration in blood, muscle, liver and carapace of the red-headed river turtle. Factors investigated included turtle length, pH, dissolved organic carbon and availability of potential methylation sites (floodplain forests and hydromorphic soils). The study was conducted in the Rio Negro basin, where the authors collected water and turtle blood, muscle, liver and carapace samples from 12 tributaries for chemical analysis.

The authors used radar imagery and existing soil maps with GIS to estimate the percentage of alluvial flood-plains and hydromorphic soils (potential methylation sites) for each drainage basin at sampling points. The mean Hg concentration in blood of P. *erythrocephala* was 1.64 ng g^{-1} (SD = 1.36), muscle 33 ng g^{-1} (SD = 11), liver 470 ng g^{-1} (SD = 313) and carapace 68 ng g^{-1} (SD = 32). Sex or length did not influence the Hg concentration in *P. erythrocephala* blood, muscle and liver, but Hg increased in carapace tissue when length size increased. In the multiple regression analysis, none of the environmental factors studied had a significant relation with blood, muscle, liver and carapace. The authors opine that even though *P. erythrocephala* moves among habitats and in the open and interconnected aquatic systems of the Amazon basin, characterized by high levels of limnological variability, yet the levels of Hg in the turtle's liver were high enough to pose a risk to humans that consume them. It suggests the usefulness of *P. erythrocephala* as a bioindicator.

Modeling nest-site occurrence for the spotted owl: Models were used to develop spatial predictions of occurrence within the study area and in adjacent ecoregions which were validated with an independent dataset. The model based on a local vegetation layer generally exhibited better performance than the model based on the more generic regional layer. Model results indicate that forest connectivity and topographic conditions, rather than forest type or age, were the strongest predictors of nesting owl presence. Predicting outside the original study area was somewhat successful for a coastal ecoregion similar in vegetation and climate, but not better than random for a nearby inland ecoregion, suggesting that locally derived models are necessary to adequately predict nest-site occurrence.

Predicting suitable habitat for the white stork and habitat restoration: The loss of wetlands and semi-natural grasslands throughout the world has led to a decline of species associated with these habitats. The reinstatement of these habitats requires spatially explicit predictions of the most suitable sites for restoration, to maximize the ecological benefit per unit effort. One species that reelects the decline in wetland areas is the white stork *Ciconia ciconia,*; the restoration of habitat for this indicator species is likely to benefit a suite of other wetland and grassland biota. Storks are also being reintroduced into southern Sweden and elsewhere.

Olsson and Rogers[32] have developed a simple predictive habitat-use model based on only a small but reliable presence-only dataset viz on the extent and relative soil moisture of semi-natural pastures, the extent of wetlands and the extent of hayfields in southern Sweden. The model was used to predict the current extent of stork habitat that is suitable for successful breeding and the extent of habitat that would become suitable with moderate habitat restoration. The model identified all 10 occupied nesting sites where breeding is currently successful. It also identified ~300 km^2 of habitat that is predicted to be suitable stork habitat but that is presently unused; these sites are recommended for stork reintroduction. The model also identified over 100 areas where moderate habitat restoration is predicted to have a disproportionate effect (relative to the restoration effort) on the area of suitable habitat for storks; these sites were identified as priorities for habitat restoration., Such habitat suitability models have the potential to maximize the effectiveness and minimize the costs of conservation programmes.

Using GIS to assess environmental risk

Surveillance of disease vector habitats and risk assessment: Dale et al[10] have demonstrated how GIS combined with remote sensing analysis, can assist in minimizing disease risk. Mapping the breeding habitats of the species *Culex annulirostris* and *Aedes vigilax*, facilitates assessment of the risk of contracting the diseases and also assists in control of the vectors. Color infrared aerial photography was used to identify the specific parts of the salt marsh in which larvae and eggs of *A. vigilax* are found. A simple risk model was applied to the field data and then linked to computer-aided analysis of remotely sensed data to map potential ephemeral breeding sites. This application has the potential to guide control at critical times, for example after heavy summer rainfall or when there is an outbreak of viral disease.

Trichinella spiralis and *Trichinella britovi* are the two most common species of Trichinella circulating in Europe. Based on data of the past 20 years covering 540 isolates of *T. spiralis* and 776 isolates of *T. britovi*, Pozio et al[40] have studied the host species and habitat characteristics for these two pathogens in Europe. A GIS was constructed using administrative boundaries, a land cover map and an elevation map. It was seen that in most countries, *T. britovi* is more widespread than *T. spiralis* (0.0-37.5%), although in Finland, Germany, Poland and Spain, *T. spiralis* is more prevalent (56.3-84.2% of the isolates). It was also seen that *T. britovi* is more widespread than *T. spiralis* in sylvatic carnivores (89% versus 11%) whereas *T. spiralis* is prevalent in both wild boars (62% versus 38%) and domestic swine (82% versus 18%) as well as in rodents (75% versus 25%). *Trichinella spiralis* and *T. britovi* circulate in the same environments: 41.1% and 46.0%, respectively in agricultural areas and 45.5% and 46.6% in forested and semi-natural areas.

Although both pathogens can be transmitted by domestic and sylvatic cycles, their epidemiology seemed to be strongly influenced by the higher adaptability of *T. spiralis* to swine and of *T. britovi* to carnivores. These results are important because they include information on the countries at risk for these pathogens, the role played by specific species as reservoirs, the role of the pathogens in domestic and sylvatic cycles and the role of the habitat in their circulation. The results can also be used to identify the most suitable animal species for the monitoring of these pathogens in Europe.

Pozio et al[40] have conducted spatial analysis to examine how temperature and other environmental factors might affect dengue fever distributions and to forecast areas with potential risk for dengue fever endemics, with predicted climatic change in Taiwan. GIS was used to demonstrate the spatial patterns of all studied variables across 356 townships. It was estimated that for every 1 °C increase of monthly average temperature, the total population at risk for dengue fever transmission would increase by 1.95 times (from 3,966,173 to 7,748,267). The likely warmer trend across the Taiwan Island is predicted to result in a sizable increase in population and geographical areas at higher risk for dengue fever epidemics.

Watershed-based cumulative risk impact analysis

Environmental vulnerability and impact criteria: A watershed-based screening tool, the Cumulative Risk Index Analysis (CRIA), was developed by Osowski et al[35] to assess the cumulative impacts of multiple CAFO (Swine Concentrated Animal Feeding Operations) facilities in a watershed subunit.

The CRIA formula calculates an index number based on: 1) the area of one or more facilities compared to the area of the watershed subunit, 2) the average of the environmental vulnerability criteria and 3) the average of the industry-specific impact criteria. Each vulnerability or impact criterion is ranked on a 1 to 5 scale, with a low rank indicating low environmental vulnerability or impact and a high rank indicating high vulnerability or impact.

Flood risk mapping: There are several ways in which GIS can be used to minimize flood risk by providing early and accurate forecasts of floods in terms of intensity as well as area-of- impact. Sinnakaudan et al[46] describe the development of ArcView GIS extension - namely AVHEC-6.avx - to integrate the HEC-6 hydraulic model within GIS environment. It has the capability of analyzing the computed water surface profiles generated from HEC-6 model and producing a related flood map in the ArcView GIS. The user-friendly menu interface guides the user to understand, visualize, build query, conduct repetitious and multiple analytical tasks with HEC-6 outputs. The flood risk model was tested using the hydraulic and hydrological data from the Pari River catchment area.

Assessment of risk of global warming: GIS can be used to overlay the best available, spatially disaggregated global data on critical impact elements (land, population, agriculture, urban extent, wetlands, and GDP), with the inundation zones projected for 1-5 m SLR. Studies by Craft et al[9] reveal that tens of millions of people in the developing world are likely to be displaced by seal level rise within this century; and accompanying economic and ecological damage will be severe for many (Figure 12). At the country level results were seen to be skewed with severe impacts limited to a relatively small number of countries.

Model simulations using the Intergovernmental Panel on Climate Change (IPCC) mean and maximum estimates of sea-level rise for the year 2100 suggest that salt marshes will decline in area by 20% and 45% respectively. The area of tidal freshwater marshes will increase by 2% under the IPCC mean scenario but will decline by 39% under the maximum scenario. Delivery of ecosystem services associated with productivity (macrophyte biomass) and waste treatment (nitrogen accumulation in soil, potential denitrification) will also decline. Thus tidal marshes at the lower and upper salinity ranges, and their attendant delivery of ecosystem services, will be most affected by accelerated sea- level rise unless geomorphic conditions (i.e. gradual increase in elevation) enable tidal freshwater marshes to migrate inland or vertical accretion of salt marshes to increase, to compensate for accelerated sea-level rise. A shift to renewable energy sources may not reduce those problems, contrary to what is popularly believed[1, 41].

Risk assessment of fire disaster: Forest and grassland fires are becoming increasingly more frequent and severe presumably due to effects of global warming. In early May 2009, several regions of northwestern India were hit by forest fires. Elsewhere also both the frequency of such fires and the losses from them are considered to be increasing with global warming and ecological degradation. A composite grassland fire disaster risk index (GFDRI) has been developed which combines the hazard of grassland fire, the exposure of the region, the vulnerability and emergency response and recovery capability. It is based on the natural disaster risk index method (NDRIM), analytic hierarchy process (AHP) and weighted comprehensive method (WCM). The risk degree of grassland fire disaster was assessed and regionalized. The study reveals that most places of western Jilin province were in 'moderate' risk; Zhenlai, Tongyu were in 'heavy' risk, and Taobei, Ningjiang, and Fuyu were in 'high' risk.

Risk of global warming to a threatened bird: Mallee Emu-wren (*Stipiturus mallee)* is a threatened, narrow-range paserine bird endemic to south-eastern Australia. To facilitate conservation measures for this poorly known species, Brown[5] used ecological niche factor analysis, habitat suitability modelling and distance sampling to determine landscape-scale habitat requirements and estimate the population size of Emu-wren. Using GIS software, he integrated digital layers of ecogeographic variables with (1) presence-only observations to derive and validate a habitat suitability model using ecological niche factor analysis and (2) distance sampling to determine population distribution and densities across vegetation types.

The studies bring out that Emu-wren is very selective about its habitat which should have mallee-Triodia vegetation that has not been burnt for at least 15 years. Due to this reason large-scale wildfires are a major threat to Emu-wren. The risk to remaining populations is heightened by the adverse impact of prolonged drought and the potential for altered fire regimes caused by global warming.

Landscape visualization techniques using GIS: Visual representations are increasingly used to communicate the impacts of environmental changes and GIS is being increasingly used to spatially organized data needed to create valid and defensible visualizations. However, the images have to be provided with detail and richness needed to generate public attention. Orland[34] describes exploratory studies in the application of techniques drawn from remote sensing and applied to ground-level photographic images of sensitive locations to achieve realistic images with demonstrable relationships to an underlying GIS. Digital filtering and image sampling processes have been used to simulate the visual consequences of forest pests, of timber management activities, of forest wildfires and of recovery from all of these impacts. The resulting images have been used to communicate expected outcomes to participants in policy-development settings and to initiate the development of public perception models relating impacts to public preferences. Although integration of these techniques with GIS systems has not yet been achieved, the necessary development steps are outlined by the authors.

Danahy[11] suggests that the visual media commonly used to structure scientific analysis, professional design, decision-making and artistic interpretation of visual landscapes are quite weak at portraying the dynamic and peripheral dimensions of human vision. The absence of a convenient, cost-effective means for showing all the fundamental visual aspects of landscape in a balanced way is a serious limitation. Author proposes that as electronic media and computational media become more developed and are applied to the realm of visual concerns, it will become more practical to include peripheral vision and dynamic viewing in deliberations about visual landscapes.

GIS based decision support systems

A web-based environmental decision support system (WEDSS) for local government planning: Sugumaran et al[50] describe the development of a Web-Based Environmental Decision Support System (WEDSS) which helps to prioritize local watersheds in terms of environmental sensitivity using multiple criteria identified by planners and local government staff in the city of Columbia, and Boone County, Missouri.

The WEDSS is an example of a way to run spatial models over the Web and represents a significant increase in capability over other WWW-based GIS applications that focus on database querying and map display. The WEDSS seeks to aid in the development of agreement regarding specific local areas deserving increased protection and the public policies to be pursued in minimizing the environmental impact of future development. The tool is also intended to assist ongoing public information and education efforts concerning watershed management and water quality issues for the City of Columbia, Missouri and adjacent developing areas within Boone County, Missouri.

Development of an integrated range management decision support system: Integrated range management decision support system (IRMDSS) has been developed by Sugumaran[49] to provide an interactive decision support tool for forest planners in the Western Ghats of India, which is one of the ecologically important areas of the Earth. The IRMDSS interface combines individual technologies such as remote sensing, a geographic information system (GIS) and a knowledge based system. The prototype IRMDSS was developed by customizing ARCVIEW GIS software and coupling it other software using dynamic link libraries. The IRMDSS prototype provides forest planners and managers a better means of organizing, accessing and evaluating a wide range of information and alternative strategies for effective forest planning and management in the study area.

Urban growth modeling on the web: a decision support tool for community planners: Compasa and Sugumaran[7] have developed a simple web-based urban growth model and visualization tool for St. Charles County's planning and zoning department to use in urban growth planning and management. They have demonstrated a web-based decision support tool for modeling urban growth under a variety of user-defined conditions utilizing multi-temporal (1984, 1992 and 2000), multi-seasonal (leaf off and leaf on) and multi-spectral Landsat images along with several other data layers such as transportation networks, demography, topography and zoning. Being web-based and operational, this model is accessible not only to urban planners but also to non-technical users from any Internet browser in contrast to other similar tools available locally on personal computers.

Conclusion

Geoarchaeology is the application of geological and geomorphological techniques to archaeology and the study of the interactions of hominins with the natural environment at a variety of temporal and spatial scales. During the last 2 decades, significant advances have been made to reconstruct the 3-dimensional stratigraphy of fluvial deposits and the matrix of fluvial sites has increased dramatically because of a number of technological advances. These have included the use of LiDAR (laser imaging) and radar to produce high-resolution digital surface models, the use of geophysics particularly ground penetrating radar and electrical resistivity, to produce sediment depth models and the use of GIS and data visualization techniques to manipulate and display the data.

These techniques along with more systematic and detailed sedimentological recording of exposed sections have allowed the construction of more precise 3-dimensional (volumetric) models of the matrix of artefacts within fluvial deposits. Additionally a revolution in dating techniques, particularly direct sediment dating by luminescence methods, has enabled the creation of 4-dimensional models of the creation and preservation of these sites. These 4-dimensional models have the ability to provide far more information about the processes of site creation, preservation and even destruction and also allow the integration of these processes with independent data sources concerning cultural evolution and climatic change.

Whilst catastrophic events clearly represent untypical and extreme situation, they can be illuminating in revealing cognitive processes resulting in abandonment, coping, mitigation and innovation. These points are exemplified using two in-depth case studies carried out by Brown[5]: one from the Holocene geoarchaeological record of the River Trent in Central England (Figure 13) and the other from the Paleolithic record from rivers in South West Britain. In the former the interaction between climate change and human activity is illustrated at the year to century timescale whilst in the other the timescale is millennial. These case studies have deliberately been chosen to be as different as possible in temporal and spatial scale with the aim of examining the applicability of methodological and theoretical aspects of geoarchaeology. The author has also considered the problem of scale in geoarchaeology and has concluded that it is the process-dependency, which ultimately affects the questions we can ask and that questions of human response to climate change are fundamentally a product of materiality and cognitive processes.

References

1. Abbasi S.A. and Abbasi N., The likely adverse environmental impacts of renewable energy sources, *Applied Energy*, **65(1-4)**, 121-144 **(2000)**

2. Amiri B.J. and Nakane K., Modeling the linkage between river water quality and landscape metrics in the Chugoku district of Japan, *Water Resources Management*, **23,** 931-956 **(2008)**

3. Aspinall R. and Pearson D., Integrated geographical assessment of environmental condition in water catchments: linking landscape ecology, environmental modelling and GIS, *Journal of Environmental Management*, **59**, 299 – 319 **(2000)**

4. Brooks R. et al, A Stream-Wetland-Riparian (SWR) index for assessing condition of aquatic ecosystems in small watersheds along the Atlantic slope of the eastern U.S., *Environmental Monitoring and Assessment*, **150,** 101-117 **(2009)**

5. Brown A.G., Geoarchaeology, the four dimensional (4D) fluvial matrix and climatic causality, *Geomorphology*, **101**, 278-

297 (**2009**)

6. Chari K.B. and Abbasi S.A., Primary productivity of Kaliveli – a rare estuarine wetland of worth Indian peninsula, *Hydrology Journal,* **26,** 1-9 (**2003**)

7. Composa E.D. and Sugumaran R., Urban growth modeling on the Web, a decision support tool for community planners, *Journal environmental planning and management* (in press), (**2004**)

8. Cowen D. J., GIS versus CAD versus DBMS: What are the differences*? Photogrammetric Engineering and Remote Sensing,* **54,** 1551 – 4 (**1988**)

9. Craft C. et al, Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services, *Frontiers in Ecology and the Environment,* **7,** 73-78 (**2008**)

10. Dale P. E. R. et al, An overview of remote sensing and GIS for surveillance of mosquito vector habitats and risk assessment, *Journal of Vector Ecology,* **23,** 54-61 (**1998**)

11. Danahy J.W., Technology for dynamic viewing and peripheral vision in landscape characterization, *Landscape and urban planning,* **54,** 125-137 (**2001**)

12. Dewan A.M. and Yamaguchi Y., Using remote sensing and GIS to detect and monitor land use and land cover change in Dhaka Metropolitan of Bangladesh during 1960-2005, *Environmental Monitoring and Assessment,* **150,** 237-249 (**2008**)

13. Dogru A.O. et al, A change detection analysis in the Izmir bird paradise: Integration of remote sensing and geographic information system, *Fresenius Environmental Bulletin,* **18,** 51-56 (**2008**)

14. Finch J. W., Monitoring small dams in semi-arid regions using remote sensing and GIS, *Journal of Hydrology,* **195**, 335-351 (**1997**)

15. Hrissanthour V., Mylopoulos N., Tolikas D. and Mylopoulos Y., simulation modeling of runoff, groundwater flow and sediment transport into kastoria lake, Greece, *Water resources management,* **17,** 223-242 (**2003**)

16. Ivkovic K.M., A top-down approach to characterise aquifer-river interaction processes, *Journal of Hydrology,* **365,** 145-155 (**2008**)

17. Jain S. K. and Goel M. K., Assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS, *Hydrological Sciences Journal,* **47,** 31-40 (**2002**)

18. Khan F.I. and Abbasi S.A., Simulation of accidents in a chemical industry using the softwarepackage MAXCRED, *Indian Journal of Chemical Technology,* **3**(**6**), 338-344 (**1996**)

19. Khan F.I. and Abbasi S.A., Accident hazard index: A multi-attribute method for process industry hazard rating, *Process Safety and Environmental Protection,* **75**(**4**), 217-224 (**1997a**)

20. Khan F.I. and Abbasi S.A., Risk analysis of a chloralkali industry situated in a populated area using the software package MAXCRED-II, *Process Safety Progress,* **16**(**3**), 172-184 (**1997b**)

21. Khan F.I. and Abbasi S.A., Risk analysis of an epichlorohydrin manufacturing industry using the new computer automated tool MAXCRED, *Journal of Loss Prevention in the Process Industries,* **10** (**2**), 91-100 (**1997c**)

22. Khan F.I. and Abbasi S.A., Inherently safer design based on rapid risk analysis, *Journal of Loss Prevention in the Process Industries,* **11(6)**, 361-372 (**1998a**)

23. Khan F.I. and Abbasi S.A., Multivariate Hazard Identification and Ranking System, *Process Safety Progress,* **17(3)**, 157-170 (**1998b**)

24. Khan F.I. and Abbasi S.A., DOMIFFECT (DOMIno eFFECT): User-friendly software for domino effect analysis, *Environmental Modelling and Software,* **13(2)**, 163-177 (**1998c**)

25. Khan F.I. and Abbasi S.A., The world's worst industrial accident of the 1990s: What happened and what might have been - A quantitative study, *Process Safety Progress,* **18(3)**, 135-145 (**1999a**)

26. Khan F.I. and Abbasi S.A., Assessment of risks posed by chemical industries - Application of a new computer automated tool MAXCRED-III, *Journal of Loss Prevention in the Process Industries,* **12(6)**, 455-469 (**1999b**)

27. Khan F.I. and Abbasi S.A., Analytical simulation and PROFAT II: A new methodology and a computer automated tool for fault tree analysis in chemical process industries, *Journal of Hazardous Materials,* **75(1)**, 1-27 (**2000**)

28. Khan F.I. and Abbasi S.A., An assessment of the likehood of occurence and the damage potential of domino effect (chain of accidents) in a typical cluster of industries, *Journal of Loss Prevention in the Process Industries,* **14(4)**, 283-306 (**2001**)

29. Lehmann A. and Lachavanne J. B., Changes in the water quality of Lake Geneva indicated by submerged macrophytes, *Freshwater Biology,* **42,** 457–66 (**1999**)

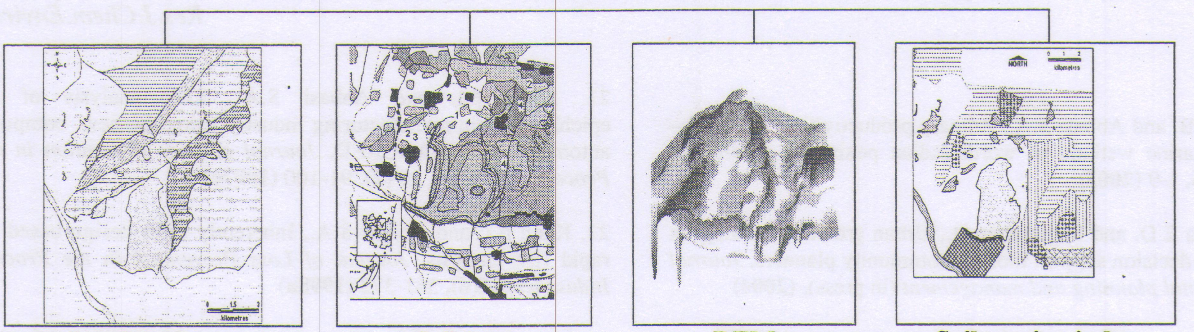
30. Marrsa S. J., Tuck I. D., Atkinsona R. J. A., Stevensona T.D.I. and Hall C., Position data loggers and logbooks as tools in fisheries research, results of a pilot study and some recommendations, *fisheries research,* **58,** 109-117 (**2002**)

31. Martin D., An assessment of surface and zonal models of population, *International Journal of Geographical Information Systems,* **10,** 973 – 89 (**1996**)

32. Olsson O. and Rogers D.J., Predicting the distribution of a suitable habitat for the white stork in Southern Sweden: Identifying priority areas for reintroduction and habitat restoration, *Animal Conservation,* **12,** 62-70 (**2008**)

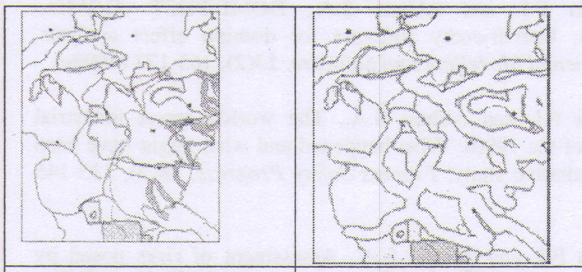
33. Olivera F. and Maidment D., Geographic information systems (GIS)-based spatially distributed model for runoff routing, *Water Resources Research,* **35,** 1155–64 (**1999**)

34. Orland B., Visualization techniques for incorporation in forest planning geographic information systems, *Landscape and Urban Planning,* **30,** 83-97 (**1994**)



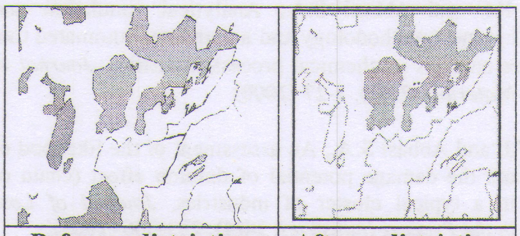
Landuse / landcover map | **Soil type** | **DEM** | **Soil erosion index map**

Fig. 1: Deriving a soil erosion index map using overlay analysis.



Before buffering | **After buffering**

Fig. 2: A drainage pattern before and after buffering



Before redistricting | **After redistricting**

Fig. 3: Three groups of land cover converted to two groups using the redistricting feature

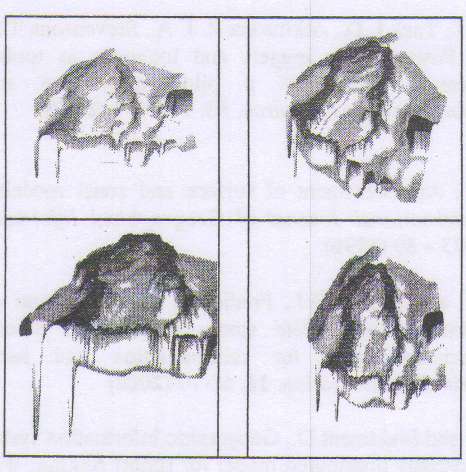


Fig. 4: Different perspectives of a 3D model (of Ossudu lake)

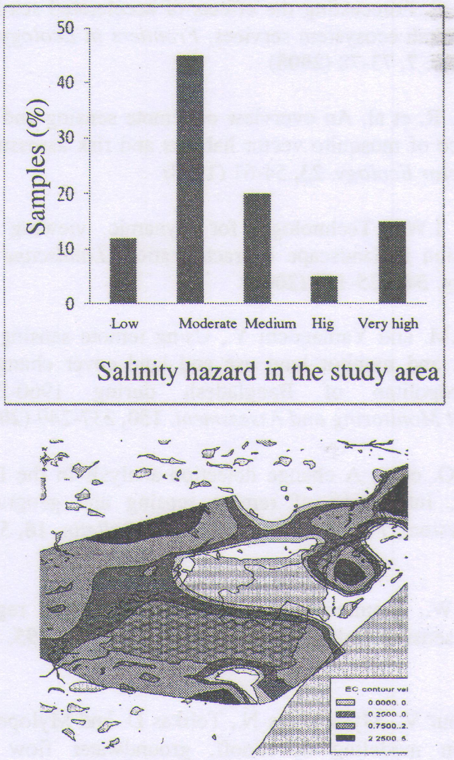


Fig. 5: Spatial data represented as a graph (left) and a thematic map (right)

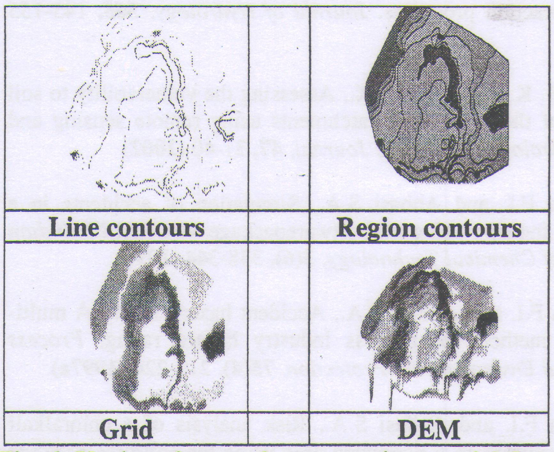


Fig. 6: Various forms of representing spatial data

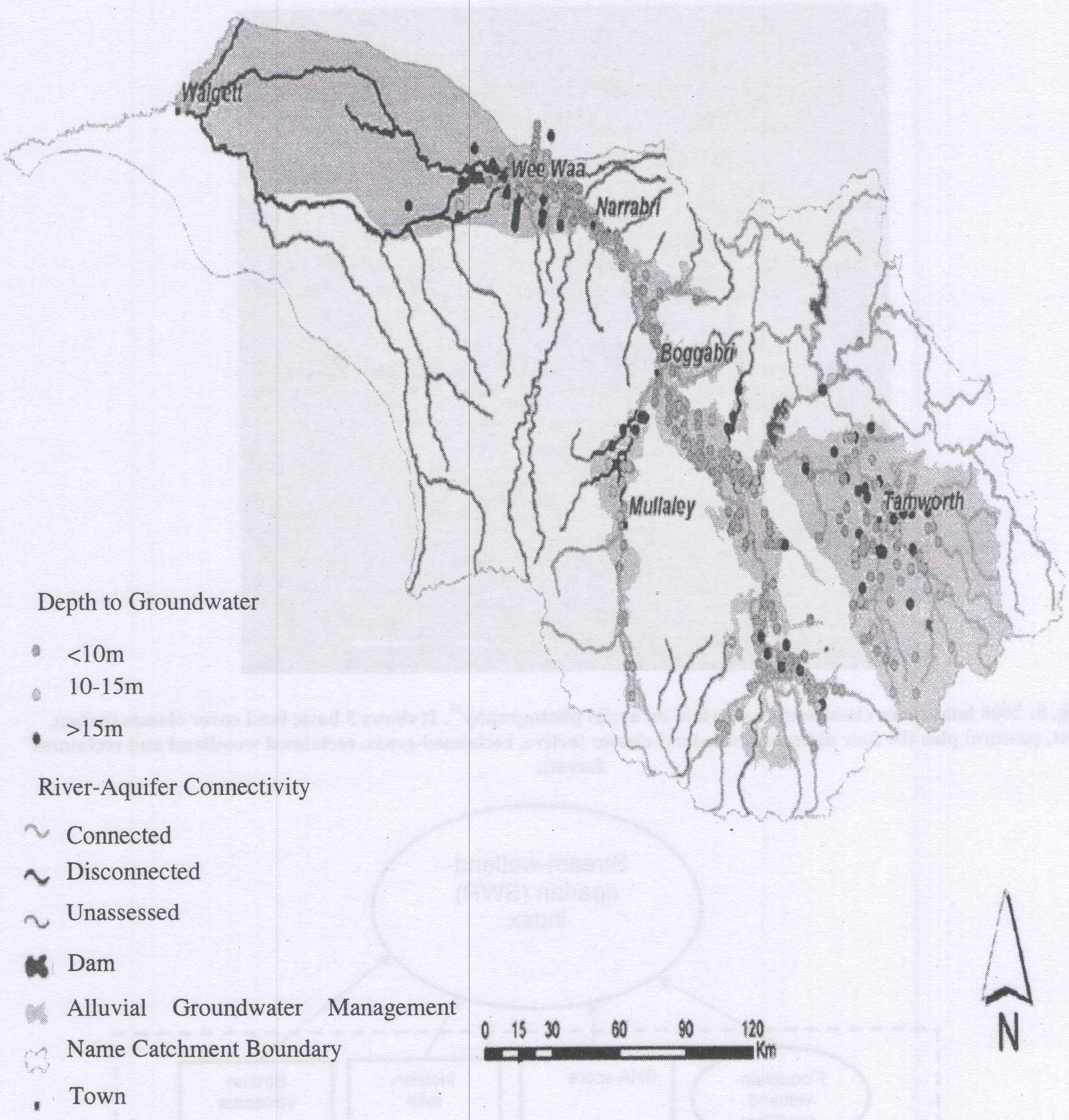


Fig. 7: River–aquifer connectivity and depths to groundwater within the shallow aquifers (<40 m) in the Namoi River catchment[16]

35. Osowski S.L. et al, A watershed-based cumulative risk impact analysis: Environmental vulnerability and impact criteria, *Environmental Monitoring and Assessment,* **66,** 159-185 **(2001)**

36. Ozemoy V. M., Smith D. R. and Sicherman A., Evaluating computerized geographic Information systems using decision analysis, *Interfaces*, 92-98 **(1981)**

37. Panta M., Kim K. and Joshi C., Temporal mapping of deforestation and forest degradation in Nepal: Applications to forest conservation, *Forest Ecology and Management,* **256(9),** 1587-1595 **(2008)**

38. Parker H. D., The unique qualities of a geographic information system, a commentary, *Photogrammetric Engineering and Remote Sensing*, **54,** 1547-9 **(1988)**

39. Paz J.M.D. et al, Use of a new GIS nitrogen index assessment tool for evaluation of nitrate leaching across a Mediterranean region, *Journal of Hydrology,* **365,** 183-194 **(2009)**

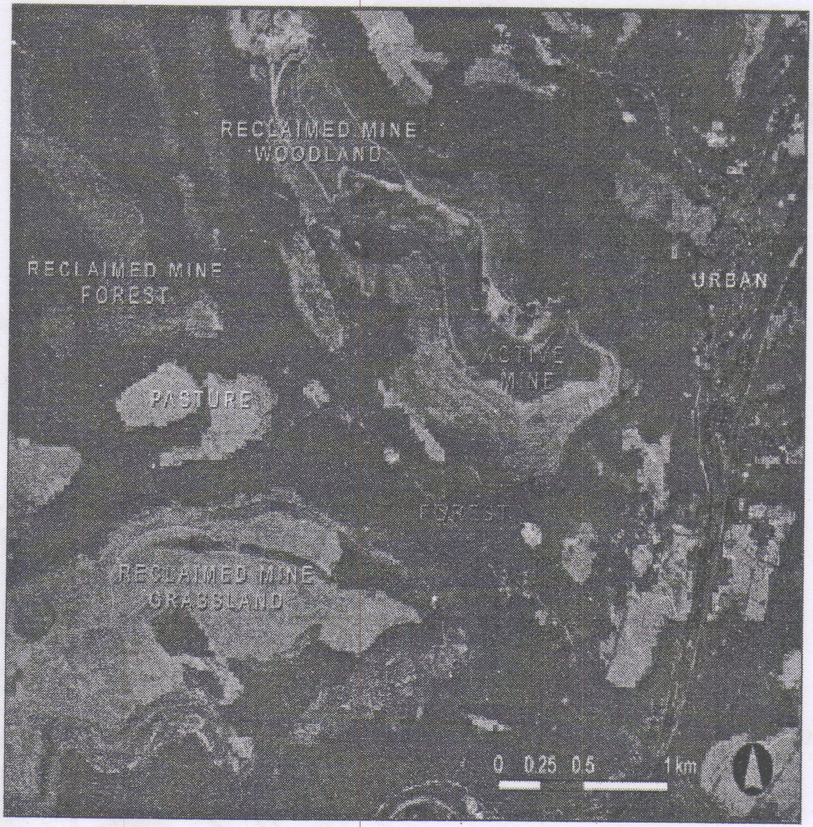


Fig. 8: 2006 land cover classification overlaid on aerial photography[51]. It shows 3 basic land cover classes (urban, forest, pasture) plus the four different mine-land classes (active, reclaimed-grass, reclaimed woodland and reclaimed forest).

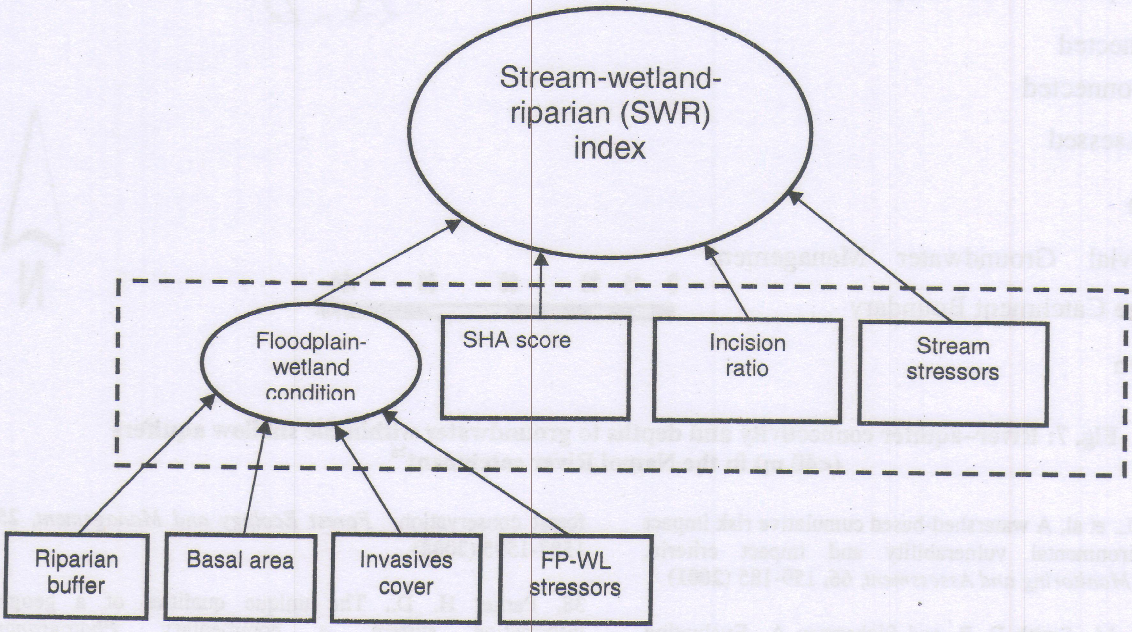


Fig. 9: The SWR index[4]

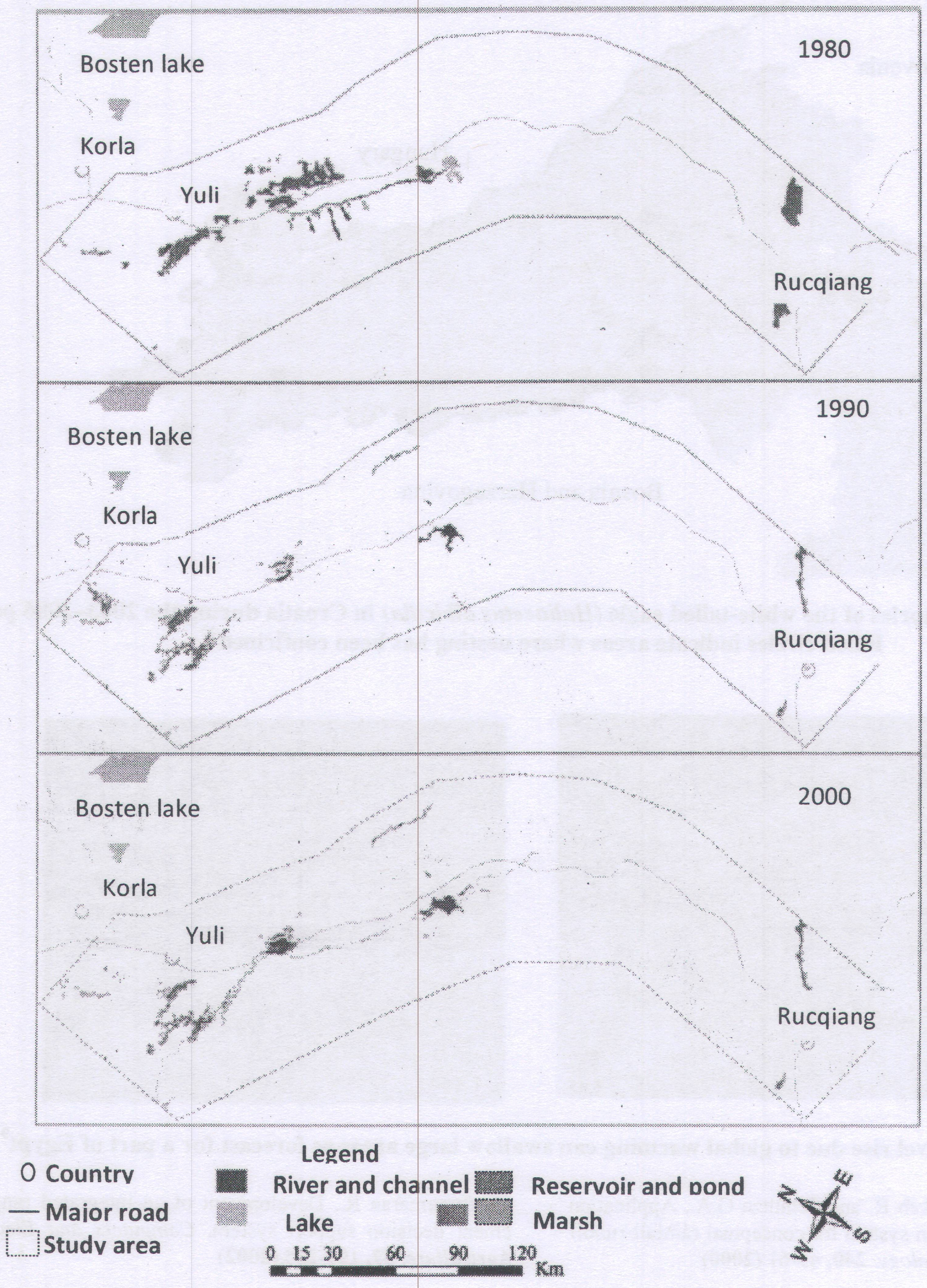


Fig. 10: Fragmentation of wetlands in the middle and lower reaches of the Tarim River over two decades

40. Pozio E. et al, Hosts and habitats of Trichinella spiralis and Trichinella britovi in Europe *International Journal for Parasitology,* **39**, 71-79 **(2008)**

41. Ramasamy E.V. et al, Feasibility studies on the treatment of dairy wastewaters with upflow anaerobic sludge blanket reactors, *Bioresource Technology*, **93(2)**, 209-212 **(2004)**

42. Radović A. and Mikuska T., Population size, distribution and habitat selection of the white-tailed eagle Haliaeetus albicilla in the alluvial wetlands of Croatia, *Biologia*, **64,** 156-164 **(2008)**

43. Rhoades E.L., O'Neal M.A. and Pizzuto J.E., Quantifying bank erosion on the South River from 1937 to 2005, and its importance in assessing Hg contamination, *Applied Geography,* **29,** 125-134 **(2008)**

44. Schulz H.K., Smietana P. and Schulz R., Crayfish occurrence in relation to Land-use properties: implementation of a Geographic Information System (GIS), *Bull. Fr. Peche Piscic*., **367,** 861-872 **(2002)**

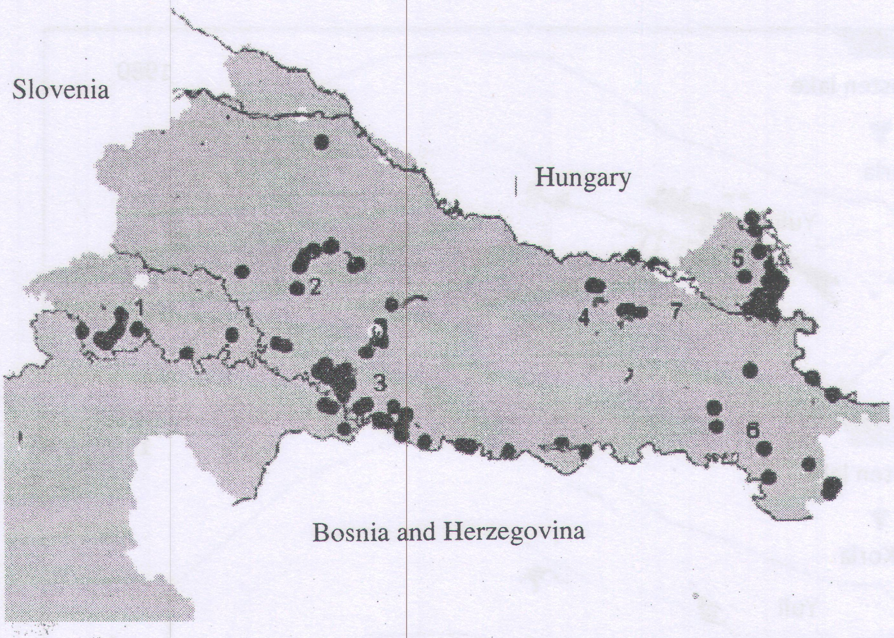


Fig. 11: Active territories of the white-tailed eagle *(Haliaeetus albicilla)* in Croatia during the 2003–2006 period. Filled circles indicate areas where nesting has been confirmed[42]

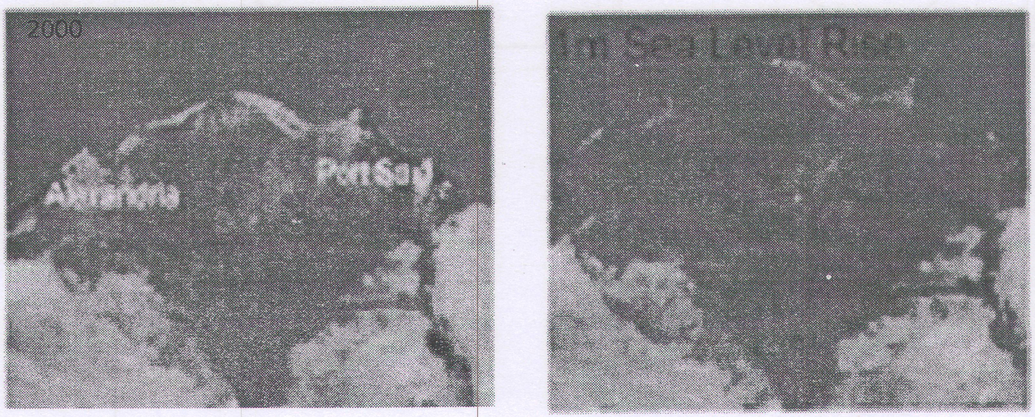


Fig. 12: Sea level rise due to global warming can swallow large areas as forecast for a part of Egypt[9]

45. Schumanna A.H., Funkeb R. and Schultza G.A., Application of a geographic information system for conceptual rainfall-runoff modeling, *Journal of Hydrology,* **240,** 45-61 **(2000)**

46. Sinnakaudan S.K. et al, Flood risk mapping for pari river incorportation sediment transport, *Environmental Modeling & Software,* **18,** 119-130 **(2003)**

47. Schneider L., Belger L., Burger J. and Vogt R.C., Mercury bioacumulation in four tissues of Podocnemis erythrocephala (Podocnemididae: Testudines) as a function of water parameters, *Science of the Total Environment,* **407,** 1048-1054 **(2008)**

48. Smith T. R., Menon S., Starr J. L. and Estes J. E., Requirements and principles for the implementation and construction of large-scale geographic information systems, *International Journal of Geographic Information Systems,* **1,** 13-31 **(1987)**

49. Sugumaran R., Development of an integrated range management decision support system, *Computers and Electronics in Agriculture,* **37,** 199-205 **(2002)**

50. Sugumaran R., Meyer J.C. and Davis J., A Web-Based Environmental Decision support system (WEDSS) for local Government Planning, *Journal of Geographical Systems,* **39,** 220-237 **(2004)**

51. Townsend P.A. et al, Changes in the extent of surface mining and reclamation in the Central Appalachians detected using a 1976-2006 Landsat time series, *Remote Sensing of Environment,* **113,** 62-72 **(2008)**

52. Wang G. et al, Factors influencing the spatial distribution of organochlorine pesticides in soils surrounding chemical industrial parks, *Journal of Environmental Quality,* **38,** 180-187 **(2008).**

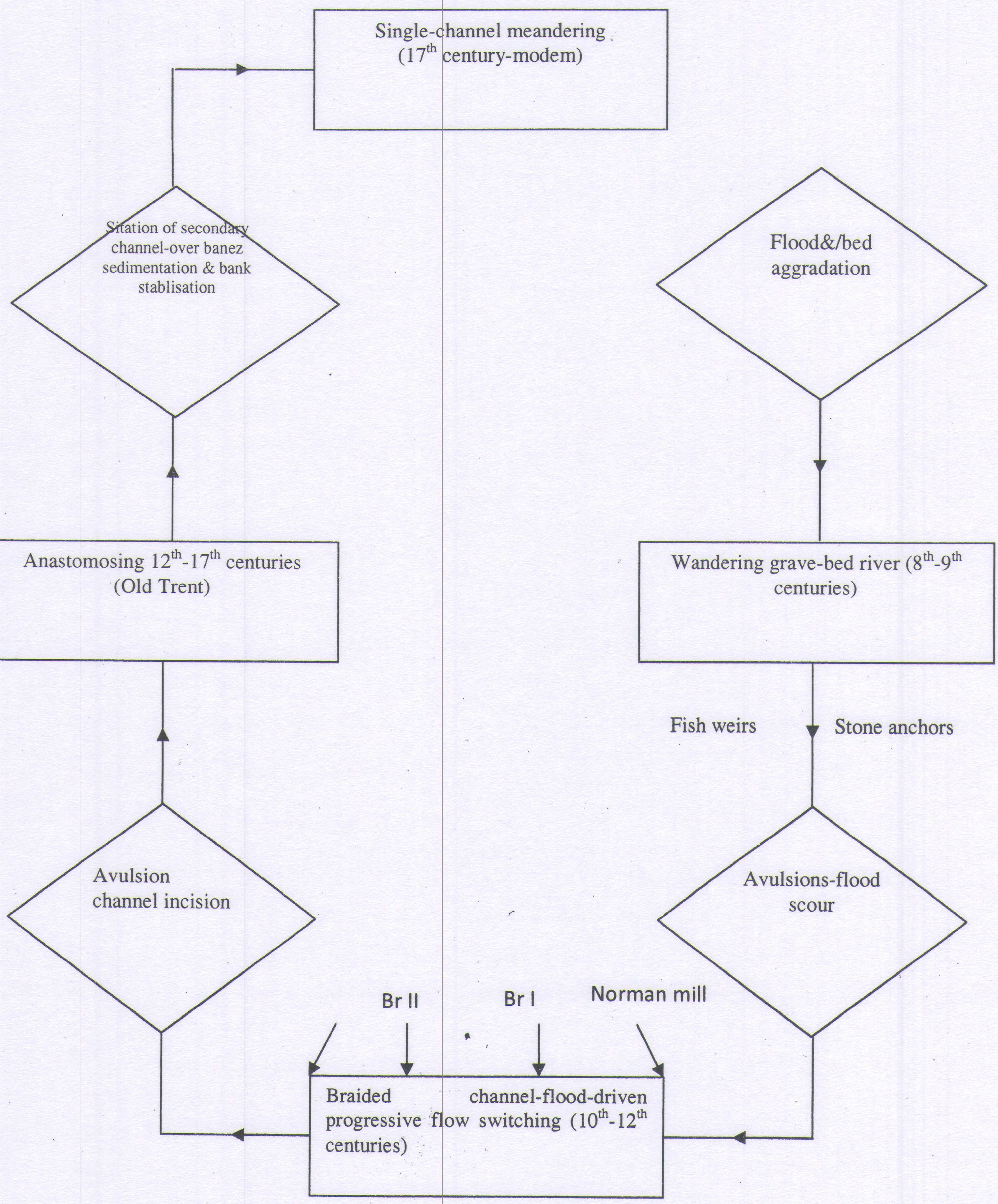


Fig. 13: Interpretive geomorphological model of channel change of the Trent River[5]

(Received 17th March 2010, accepted 25th August 2010)

Printed and published by Dr. Jyoti Garg, Sector AG/80, Scheme 54, A.B. Road, INDORE for "Research Journal of Chemistry and Environment", Sector AG/80, Scheme 54, A.B. Road, INDORE. Printed at Print Pack Pvt. Ltd., INDORE. Editor-in-Chief (Honorary) - Dr. Shankar Gargh