GIS and Remote Sensing in the Study of Land Use Effects on Water Quality

The negative effects of land use on water quality are important issues of the modern world due to the continued increase in the human population, and the subsequent increase in urbanization and food production. Agricultural land use, urbanization and deforestation can all have significant impacts on water quality if they are not managed correctly. The presence of heavy metals and volatile organic compounds, excess levels of nitrate and phosphate, and increased suspended solids are just some examples of the types of water quality issues that can occur due land use pollution. As the population continues to grow, it is imperative to maintain high water quality standards, both for human health and for the health of natural ecosystems. The study of the effects of land use on water quality has benefited immensely from the use of GIS and remote sensing in recent years. Scientists have used GIS and remote sensing to gain a better understanding of the interaction of land use and water quality at a watershed level, and how this data can be used to inform management decisions in the future.

A common way that GIS has been utilized recently is by coupling GIS with hydrologic modeling. Hydrologic modeling allows a user to predict changes to water quality or flow based on various inputs that may include land use percentages, soil type, or best management practices. Pairing hydrologic modeling with GIS has allowed scientists to customize the models for the geospatial specifics of a particular watershed. Fan et al. (2014) point out that using models associated with GIS allows for users to study larger watersheds and to include smaller streams and tributaries rather than only large rivers. Elliot et al. (2015) discuss the ability to change land use type from the default scenario by drawing in polygons where you want to place them on the map. This allows for a more visual understanding of the different scenarios. Another benefit of an integrated GIS/modeling system is the ability to generate a map as the end result.

Many scientists have also recently used different remote sensing systems to improve land use/water quality analysis. Both Singh et al. (2012) and Ayana et al. (2015) evaluate the possibility of using a model based off of MODIS to predict stream water quality. They point out some of the advantages of using MODIS, including that the data is free, is regularly updated, and the images are already preprocessed. Both studies compared traditional water quality sampling
results with results generated from a model based on MODIS images, and obtained moderate results. There is room for improvement in predicting water quality based on MODIS, but as Ayana et al. point out, models of this type could prove essential in the future for studying water quality in remote locations that are difficult to access, or developing countries that lack the resources to do traditional water quality sampling, but often have significant water quality needs.

Finally, some scientists have used GIS simply to spatially link water quality parameters to land use. Using basic GIS analyses and commands, users are able to visually display areas of a watershed that have high concentrations of a certain contaminant, as well as high percentages of a certain type of land use. Statistical analyses are also often used to establish the relationship between certain pollutants and certain types of land use. Tong and Chen (2002) used both statistics and GIS analyses to link urban and agricultural land use with high levels of nitrogen and phosphorus on a regional scale. Vendeberg et al (2015) spatially linked nitrate in a wildlife refuge to swine feeding operations upstream by mapping land use and the locations of water quality monitoring sites within the watershed.

The future of GIS and remote sensing in the study of land use effects on water quality seems to be leading to the concurrent use of multiple different methods in order to gain an understanding of water quality at the watershed level. Almost all of the studies that I read used more than one type of analysis, whether it was GIS coupled with hydrologic modeling, or remote sensing coupled with traditional water quality sampling procedures. It is clear that GIS and remote sensing have become essential tools in analyzing land use effects on water quality, and will continue to become more useful in the future of water resource management.

**Annotated Bibliography**


Tong and Chen used a combination of statistical analysis, GIS spatial analysis, and water quality monitoring to determine the effects of different types of land use on surface water quality. Their approach was unique for the time because they integrated multiple different analyses to look at land use effect on water quality. Many of the previous studies only utilized statistics, or only utilized hydrologic modeling. Using these methods, their goal was to identify specific regions of the watershed that had a strong relationship between land-use and contaminants. The GIS aspect of their study involved creating a shapefile of the locations of monitoring stations throughout a watershed, including an attribute table of the water quality parameters associated with each station. They performed an overlay of the water quality data.
on top of a basemap that divided the watershed into HUCs. They then added land-use data to each HUC and classified the HUCs based on percentage of each type of land-use. They also classified the water quality variables into high, medium or low concentrations, then created a map that depicted the spatial relationship between them. For example, HUCs with high percentages of agricultural land use and high nitrate concentrations were mapped. The researchers then used a hydrologic model to simulate how changes in land use might affect water quality. They point out that their integrated approach might allow scientists in the future to better predict water quality changes with land use at the watershed level.


Ayana et al. looked at the effectiveness of using a dataset established from MODIS images to model total suspended solid emission at the river mouth of Lake Tana in Ethiopia. The authors point out the advantages of using MODIS data in a developing country, where it is not common to have accurate, long term, continuous water quality data from traditional water quality measuring techniques due to a lack of money and people to monitor the data. Using a dataset from MODIS would allow scientists to acquire water quality data on a regular basis (MODIS has a 1 to 2 day re-sampling period) and to cover the entire watershed, rather than a single point. The scientists compared TSS data in the field over a ten-year time period to results of the same ten-year time period generated from a model based on MODIS images. They statistically established a relationship between reflectance and TSS, and then entered that data into the SWAT modeling system to simulate TSS emissions over the ten years. Their results indicated a “modest performance” between the modeled data and the actual data. The scientists point out some of the limitations they encountered, including the complex nature of TSS transport in a watershed, a somewhat small (10 year) sampling period and limitations of the model.


Similarly to the above study by Ayana et al., this study by Singh et al. looked at the effectiveness of using a model generated from MODIS images to predict nitrate and phosphorus concentrations in a Wisconsin stream. The scientists pointed out that the most commonly used land use data derived from remote sensing images is generally outdated. MODIS images, on the other hand, are frequently updated so a more accurate, continuous dataset could be produced from them. Like Ayana et al., they compared in situ measurements of nitrogen and phosphorus with the results of the model based on data derived from MODIS images of the same time period. The model worked well for predicting nitrate, but not as well for predicting phosphorus. In future studies the scientists suggest aggregating watersheds into small, medium and large groups by area, and including topographic variables in the model to increase its accuracy. They also point out that models of this sort could be used in the future to identify watersheds in need of restoration, and identify what areas to target to improve water quality based on land use and nitrate/phosphate concentrations.

This study looked at the impact that runoff from swine feeding operations had on the water quality of the Lake Alice National Wildlife Refuge in North Dakota. They used statistical analyses to spatially link water quality parameters such as total organic carbon with nearness to animal feeding operations. They also used GIS to map the spatial distribution of water quality in the refuge in relation to the animal feeding operations. To do this, the scientists collected water samples in the field and analyzed them in the laboratory, then loaded this data, along with watershed, land cover data and the locations of the water sampling locations into GIS. Some of the tools they used to do this included clipping the data sets so that only the area of interest was displayed, measuring the distances between animal feeding sites and water sampling locations, and doing calculations to determine the percentage of each land cover type. Their results showed significant variation in water quality data based on sampling location and a strong correlation between certain water quality parameters and percentage of animal feeding locations. Future studies may involve determining if best management practices can help address some of the water quality issues in the wildlife refuge.


This article looks at coupling GIS with a water quality model to model the fate of point source pollutants under different flow scenarios. Coupling GIS with hydrologic models is a common occurrence, and the authors point out that over the past couple of decades, the use of GIS with hydrologic models has improved, leading to the full integration of GIS into the models, or vice versa. The authors state that mathematical models are essential for simulating the movement of pollutants in water bodies, but they point out that these models also often have some limitations. These limitations include only being capable of representing a small river reach rather than an entire watershed, focusing only on large rivers and not including smaller tributaries, and simulating only one pollutant source and one point of interest. Coupling a model with GIS can eliminate some of these problems. For this model, the authors used MapWindow GIS. The GIS coupled model consisted of geospatial watershed data, including the slope, length, width, and drainage area of each river reach, flow for each river reach, and pollutant specifications. The authors compared the model results to a tracer test and determined that the model showed an “adequate performance”, and suggested for future studies to modify the model to include more specifics such as location of reservoirs in the watershed.


This study used PRISM (airborne portable remote imaging spectrometer) to obtain high-resolution water quality data for the highly human-impacted San Francisco Bay-Delta Estuary. The San Francisco Bay-Delta Estuary provides most of the water supply for California, yet it has some significant water quality issues due to surrounding agricultural land use and habitat isolation due to flow changes. It is therefore very important to monitor the water quality of the estuary, and historically this has been done using 30 water quality monitoring stations throughout the ecosystem. The authors point out that this system lacks continuous spatial coverage that water quality data from remote sensing could provide. The scientists collected water quality data including turbidity, suspended solids, and dissolved organic matter using both in situ measurements and remote sensing measurements. Water quality data was derived from PRISM by associating certain wavelengths of light with certain water quality parameters. The
results of the two data collection methods were compared and it was determined that the PRISM water quality predicted water quality very well. The authors predict that in the future, the use of remote sensing such as PRISM will allow scientists to more easily identify the sources of pollution in a waterway, observe the effects of restoration efforts, and promote water management on a more holistic watershed scale.


This study comes from a group of scientists in New Zealand, where the use of hydrologic modeling has become essential for predicting changes in water quality in light of growing agricultural land use. This paper does not involve any data acquisition or analysis, but rather the authors give a thorough evaluation of the CLUES (Catchment Land Use for Environmental Sustainability) model, which combines GIS with traditional water quality modeling parameters. Some of the spatial parameters that the model uses include land use, drainage network, slope, and point sources of pollutants. Attributes for each section of a watershed can also be included in the spatial data, such as average rainfall. The end product of the simulation can either be a numerical result or a map, which is one of the benefits of coupling models with GIS. Some examples of situations in which CLUES has been used include modeling how E. coli concentrations may change with increasing agricultural land use and modeling changes in nutrient loading and eutrophication based on land use changes. In terms of improvements to the GIS portion of the model, the authors suggest moving to a free web-based platform rather than ARCGIS to make it more user-friendly for those without a strong GIS background.