Review of Qihao Weng's April 2002 article "Land Use Change Analysis in the Zhujiang Delta of China Using Satellite Remote Sensing, GIS and Stochastic Modelling"

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Part I
Summary

1 Background

Chinese economic growth following the 1978 reintroduction of the open-door policy has been accompanied by dramatic urbanization and industrial development. Consequently, regions experiencing the greatest increases in economic activity have also seen significant change in land use over this recent period (e.g. urban sprawl and the disappearance of cropland). Notably, rapid change in land use has in turn interfered with previous, sustainable agricultural practices, such as the dike-pond system used in the Zhujiang Delta, and otherwise threatened environmental sustainability. In order to inform environmental management efforts and to achieve sustainability in development, it is important to understand current trends in land use and thereby to gain insight into the kinds of pressures land use change may place on the environment in the future.

Analyzing satellite images, Indiana State University Professor of Geography Qihao Weng uses stochastic modeling to investigate long-term predictability of land use change in the Zhujiang Delta of China. Weng's 2002 paper "Land Use Change Analysis in the Zhujiang Delta of China Using Satellite Remote Sensing, GIS and Stochastic Modeling" examines transitions between seven categories of land use inside a 15,112 square kilometer area of the delta during the years 1989-1997. As a site of Special Economic Zones and a "model for Chinese regional development" (Weng 275), the Zhujiang Delta presents a particularly relevant case for studying trends in the growth/decline of these land use categories.

Research Design/ Method

Looking at satellite images of the delta taken in 1989, 1994, and 1997, the author designates seven land use categories into which hectares are sorted according to spectral bands: "(1) urban or built-up land, (2) barren land, (3) cropland (rice), (4) horticulture farms (primarily fruit trees), (5) dike-pond land, (6) forest, and (7) water" (Weng 276). The study models land use change as a Markov chain and uses "fine changes in surface reflectances" (Weng 276) to detect transitions between the above categories, which are thus the states of the chain.

According to the Markov hypothesis, the state of the chain at any given time is dependent only on the immediately preceding state and not on any other historical information. In order to validate the assumption that land use change is a Markov process, the author first determines whether or not transitions on each hectare in the study area from one land use category to another between 1994 and 1997 are statistically independent of transitions between 1989 and 1994. The test can be done by comparing the number of hectares that actually transition from state i in 1989 to state k in 1997 with the number expected according to the Markov hypothesis. If the Markov hypothesis holds, we should not find independence at this point, since the state of any hectare in 1997 should be dependent on its state in 1994, which in turn should in fact depend on its state in 1989. The expected number $\mathbf{N_{ik}}$ transitioning from i to k is calculated as follows:

$$\mathbf{N_{ik}} = \sum_j (N_{ij})(N_{jk})/N_j$$

with N_{ij} the actual number of hectares transitioning from i to j between 1989 and 1994, N_{jk} the number of transitions from j to k between 1994 and 1997, and N_j the number of hectares in state j in 1994. The author then calculates Carl Pearson's χ^2 with $(M-1)^2$ degrees of freedom, which he names K^2 to avoid confusion with its distribution (chi square):

$$K^2 = \sum_i \sum_k (N_{ik} - \mathbf{N_{ik}})^2/\mathbf{N_{ik}}$$

with N_{ik} the actual number of hectares transitioning from state i in 1989 to state k in 1997. With seven land use categories, we have $M = 7$. Using a 0.05 critical region, a value of K^2 less than 55.8 would indicate that the 1994-1997 transitions are independent of the 1989-1994 transitions (which would contradict the hypothesis that states of land use in 1997 did in fact depend on states of land use in 1994).

Next, if the above described test returns a value of K^2 more than 55.8 (which it does), the author uses a chi-square goodness-of-fit test to determine whether or not the data are consistent with a Markovian distribution–meaning that the 1994-1997 transitions are in fact dependent only on states of land use in 1994, independent of each hectare's state in 1989. This is thus a test for first-order Markovian dependence, described by Baker to be the condition that "the probability of a particular set of outcomes depends only on the current distribution among states and the transition probabilities, so that history has no effect" (Baker 117). The χ_c^2 statistic is calculated by:

$$\chi_c^2 = \sum_i \sum_k (O_{ik} - E_{ik})^2 / E_{ik}$$

with O_{ik} the observed transition probability, calculated using N_{ik} and N_i (number of hectares in state i in 1989), and E_{ik} the expected transition probability, calculated using $\mathbf{N_{ik}}$ and N_i. With a critical region $a = 0.05$ and $(m-p-1)^2$ degrees of freedom, where m is the number of land use categories and p is the number of parameters estimated from the data, in the case that

$$\chi_c^2 > \chi^2_{1-a,(m-p-1)^2}$$

we would reject the hypothesis that the Markovian distribution describes the data.

In order to investigate future predictability of land use change, Weng calculates stationary distributions from the matrix of expected transition probabilities for the years 1989-1997, as well from the matrix of observed transition probabilities for the years 1989-1997, the transition matrix for the years 1989-1994 and the transition matrix for the years 1994-1997. If repeatedly multiplying each of these matrices with itself eventually results in the 1989-1994 and 1994-1997 stationary distribution calculations approaching the same limit, then this would suggest that the forces driving land use change have been similar throughout these intervals, and thus that land use change is stabilizing. We could in this case obtain useful estimates of the probabilities that a given hectare will be in each of the seven states far in the future (i.e. steady-state probabilities from the 1989-1997 transition matrix).

Results and Analysis

Weng finds a K^2 value of $1.6425 * 10^5$. Since this greatly exceeds 55.8, it is apparent that the states of land use in 1997, 1994, and 1989 are not statistically independent of each other. Next, a χ_c^2 value of 0.5731 and $\chi^2_{0.95,36}$ value of 29.1 indicate we may hypothesize at the 5% level that land use change is a Markov process. In other words, though states of land use in 1994 are dependent on states in 1989, transitions between states during 1994-1997 are dependent only on the 1994 states.

With regard to the stabilization of land use change, the stationary distributions calculated from the transition matrices for the periods 1989-1994, 1994-1997, and 1989-1997 are very different. For example, the steady-state probability of a given hectare being in the "dike-pond land" state is 0.1055 when found using the 1989-1994 transition matrix, and 0.0308 using the 1994-1997. The author deems that the process of land use change in the region is thus not currently stationary. Nevertheless, Weng notes that if the process were stationary, the 1989-1997 matrix of transition probabilities would tell us that in the distant future, “7.14% of land will be urban or built-up, 0.58% will be barren land, 11.37% will be cropland, 24.19% will be horticulture farms, 5.1% will be dike-pond land, 11.76% will be forest, and 39.39% will be water” (Weng 282). The author concludes that though the mechanisms repsonsible for land use change still appear to be evolving (and thus that today’s transition probability’s may not apply in the future), “Markov chain models have shown the capabilities of descriptive power and simple trend projection for land use and land cover change, regardless of whether or not the trend actually persists” (Weng 282).

Part II
Critique

Possibilities for a More Descriptive State Space

Weng’s model is useful for describing land use change in terms of degree of industrialization and economic development. The states that the author chooses seem to represent a meaningful range of levels of development: “forest,” “water,” and “barren land” are likely good indicators of low development, while agricultural land might indicate varying levels of moderate development according to the technical sophistication of the agriculture taking place, and “urban or built-up land” obviousy signifies relatively high development.

However, greater specificity may be necessary with regard to the “urban or built-up land” category, since different types of built-up land may have significantly different environmental impacts. For example, factories may produce more waste and/or waste of a more harmful variety than residential neighborhoods, and we may thus be interested specifically in the future prominence of factory land. In fact, the level of environmental disruptiveness caused by a piece of land’s current use may partly determine the likelihood of that land being put to other uses in the future. Industrial waste sites and other dumping grounds, for instance, may have a lower probability than residential neighborhoods of transitioning to the “cropland” state due to the very fact that the activity of waste disposal reduces the local environment’s capacity to support farming.

Furthermore, evolution of the mechanisms driving land use change, which in this study precluded finding stationarity in the process, may be partially resolved by including more states. Suppose, hypothetically, that soda-bottle factories transition into either forest land or office buildings, and that office buildings have no chance of transitioning into anything less “urban or built-up.” If over time, office building land increases relative to bottle factory land, then the “urban or built-up land” state would exhibit a decreasing probability of transitioning to the “forest” state.

Comparison with Alternative Approaches

Unlike the author's method of modelling land use change, which tracks transitions between usage categories on each individual unit of land, other models have only accounted for change in the overall distribution of land between categories over time (Baker 113). Such an approach, however, would not allow the study to calculate transition probabilities between states. We might know, for example, that there is now a larger amount of urban and barren land, with less cropland and forest than in the past–however, we would not know how much forest land has become barren, how much barren land has become urban, etc. As "data and computational limits are becoming less significant" (Weng 283) due to technological advances, Weng's approach provides greater insight into "how and why" land use change occurs (Weng 274).

Also, certain models use birth and death functions to track the growth/decline of land features (Baker 114), for example a desert or lake. Weng's study does not use birth and death functions to model the growth of cities and industrial sites, because it is concerned with how that industrialization has affected specifically the balance of land types in a fixed area. Hence, the author aims to determine what urban growth means for the presence of farmland, forest and water in the surrounding region, rather than simply to predict the future rate of urbanization.

Finally, while other studies might use a continuous state space (Baker 113), the author chooses a discrete state space of seven categories. In a continuous space, the "states" would differ from one another on a single characteristic: for example dryness, or degree of vegetation. Though this may be appropriate for studying change in land cover, it would be less useful in a study of change in land use, since no single characteristic of a unit of land may suffice to meaningfully describe its purpose. We might, for example, classify hectares of land in the study region according to prevalence of water, but this would not necessarily distinguish between urban and barren land.

References

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