New model developed for research into 'social-ecological systems'

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A new mathematical model allows researchers to better understand and plan the designs for infrastructure to account for human factors in systems ranging from small-scale agriculture to urban infrastructure.

"The problem I see and addressed in this research is that our view of social-ecological systems is incomplete because it misses a critical linkage, which is the role of infrastructure," said David Yu, an assistant professor of civil engineering and political science at Purdue University.

He used his mathematical dynamic model to study small-scale irrigation systems in Nepal as a test case, but the same approach can be used to study myriad types of infrastructure-mediated systems. The research revealed two design features that can induce fundamental changes in qualitative behavior of such irrigation systems.

"The same conditions apply to systems in developed countries as well as developing countries," he said. "Social-ecological systems are everywhere. National parks, fisheries, irrigated agriculture. Any time you have people interacting with ecosystems there is some kind of infrastructure such as dams, canals, levees, roads, fishing boats, port facilities, processing facilities. There is a pervasive presence of infrastructure, and how it is designed can cause fundamental regime shifts in how the system works."

Findings are detailed in a paper that appeared online this month in *Proceedings of the National Academy of Sciences*.

A better understanding is especially necessary in a world marked by global change, when economic shocks such as the introduction of factory jobs and other employment opportunities can disrupt rural social-ecological systems that have been in place for decades or centuries.

"In social-ecological systems human societies and ecosystems are no longer separate," Yu said. "They are intertwined systems and they are dependent on each other. However, people have generally failed to recognize the two systems are intertwined, and this has led to recurring environmental problems."

One example of the human mismanagement of a social-ecological system is forest-fire suppression in Yellowstone National Park.

"Managers thought it would always be better to suppress major fires to maintain the forest, but it turns out that by suppressing fires you are building massive biomass more sensitive to major fire events in the future," he said.

Another example is international aid organizations coming to a rural village and modernizing infrastructure.

"This is well intentioned, but it can backfire because it could actually undermine and harm the ecosystem function, the traditions villagers have built over hundreds of years to maintain their irrigated agriculture," said Yu, who developed the model as part of his doctoral thesis at Arizona State University.

He likened the use of community irrigation systems to a biologist's use of fruit flies as a model organism to study evolutionary biology.

"That is, I study an irrigation system here as a model system of social-ecological systems (SESs), as in the sense that biologists use the fruit fly, worms, or mouse as a model organism when they do their research," he said. "I believe irrigation systems contain basic features of complex SESs. People need to work together to invest in a public infrastructure to direct natural processes for their benefit and coordinate the distribution of benefit streams in a fair manner. These situations are vulnerable to social dilemmas, and humans need to cooperate to solve these dilemmas."

In irrigation systems, public infrastructure generates a "benefit flow" that is distributed back to the people who contributed. The structure of this benefit flow could be either symmetric or asymmetric. In asymmetric flow, some people receive their benefits before others because they are upstream of the irrigation canal, whereas those downstream receive water later.

"This happens even though everybody has to contribute to the system at the same time," he said. "So people downstream are disadvantaged."

The asymmetric access amounts to an inequality that could prompt the disadvantaged participants to withdraw from the system, representing a threat to its continued operation.

"So design of the infrastructure can have a causative effect," he said.

In symmetric distribution, everyone receives benefits at the same time, which also carries its own potential vulnerabilities.

"When I varied all scenarios the symmetric system could only have two outcomes: collapse or maintained," Yu said. "However, with asymmetric flow I looked at all scenarios using my model and it showed that there are three regimes or long-term system behaviors: collapse, a sustainable outcome, or decoupled, which means inequality."

More information: David J. Yu et al. Effect of infrastructure design on commons dilemmas in social−ecological system dynamics, *Proceedings of the National Academy of Sciences* (2015). DOI: 10.1073/pnas.1410688112

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