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Oasification and Desertification under the Framework of Land Degradation Neutrality †

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Abstract: To meet population growth, the excessive abstraction of water resources for irrigating water-intensive crops has become an increasing crisis in arid regions of Northwest China. This dynamic, typical of drylands, contains the perennial contradiction between development and desertification, which we also find within the United Nations Convention to combat Desertification (UNCCD), where some interpret it as a developmentalist convention and others as a conservationist one. Land Degradation Neutrality (LDN) concept, has been set up as the main tool to combat desertification by the UNCCD and is included in SDG 15.3. LDN refers to a state of zero net land degradation, where "the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems". Under the LDN framework, we apply two of its main pillars, prevention and land planning. The aim is to understand the underlying biophysical and socio-economic mechanisms of oasis expansion in NW China, a phenomenon known as oasification. The objective is to detect under what conditions oasification tackles desertification and when it triggers land and economic degradation. From this knowledge it will be possible to propose guidelines of action to balance land use and comply with LDN.

Keywords: oases; cash crops; irrigated agriculture; land-use planning; causal diagrams; System Dynamics; NW China

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1. Introduction

China is one of the countries affected seriously by desertification [1]. China has 6.6 million km^2 of drylands (expanded by 8.3% during 1980–2015 [2]) that support approximately 580 million people [3]. It is in this vast territory where desertification occurs, i.e., the degradation of drylands due to climate variations and inadequate human activity [4]. Desertification affects seven main dryland provinces and autonomous regions (Xinjiang, Inner Mongolia, Tibet, Qinghai, Gansu, Ningxia and Sha'anxi) and 12 main deserts and sandy lands [1]. Although the ambiguity of this complex problem makes it difficult to assess and map [5,6], it is estimated that the direct annual economic loss caused by desertification is RMB 33.1–94.9 × 10^9 [7]. In addition to these effects, the irreversible nature of desertification narrows the development options of a territory [8], and poverty will be exacerbated [9].

In NW China, the most recognizable expression of desertification is a serious water scarcity [10]. The increasing water gap results both from the falling supply of water, and the rising demand for water. The former is related with the effects of climate change.

Climate projections in China point to a greater risk of extreme events and aridification in arid and semi-arid regions. In addition, changing snowmelt patterns [11] are a serious threat to the region's oases, which have historically depended on this water flow [12].

The latter is explained by the fast transition from food crops to cash crops. The change in land use was triggered in the early 1980s, when farmers were given more autonomy in land use [13]. In the least developed regions farmers have few choices for increasing their income (i.e., their opportunity cost is low) besides expanding their agricultural scale [14]. Hence, this oasification process—the natural or artificial expanding the boundaries of oases—has a double edged, as it can tackle or favor desertification. Oasification leads to a greater vegetation cover in places that, due to low rainfall, is very sparse or inexistent. In addition, the quality and quantity of the soil is improved, as shown by various indicators (e.g., soil organic carbon). However, oasification can result in the extensive lands being abandoned due to water shortage [15], threatening its very survival. We are, therefore, faced with an archetypal problem in drylands: it is necessary to promote economic development and try to take advantage of water resources to green the landscape, but poor management of these resources can cause the whole system to collapse (i.e., lead to desertification).

This is the ambiguity of the concept of desertification, which basically stems from all that the definition of desertification [16]—recall that it is the degradation of drylands-includes in the word degradation: "the reduction or loss of the biological or economic productivity, complexity of ecosystems, and biodiversity" [4]. This controversy explains why the UNCCD has been so ineffective, embodied the conflicting expectations of Parties: developing countries regard it mainly as a development convention, while developed countries regard it as an environmental convention [17]. This dilemma is not only found in desertification, but also in the Sustainable Development Goals (SDGs), where there are important (and irresolvable) trade-offs between environmental goals (e.g., SDGs 13 or 15) and economic growth goals (e.g., SDGs 1, 2, and 8). The answer to this dilemma can be provided by Land Degradation Neutrality (LDN), with which the UNCCD could re-energize international action on desertification and regain lost protagonism [18].

LDN is defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems". LDN has been set up as the main tool to combat desertification in SDG 15.3. LDN is a pragmatic because it links "development" and its implicit, associated economic benefits to restoration commitments, including offsets. It could be achieved by: (a) managing land more sustainably, which would reduce the rate of degradation; and (b) increasing the rate of restoration of degraded land, so that the two trends converge to give a zero net rate of land degradation.

This research will delve into the socio-economic drivers of oasification, where a research gap has been detected [16]. To this end, causal diagrams –one of the first stages of System Dynamics (SD) modeling [19]—will be used to understand the mechanisms underpinning oasification processes by detecting feedback loops, nonlinearities, and delays between variables. Gaining an in-depth comprehension of the functioning of the socioecosystem paves the way for proposing solutions in the framework of LDN [20].

2. Methods

Modeling can be an important technique in analyzing and describing processes of desertification change in addition to furthering our understanding of the relationship between the socio-economic and ecological factors involved and their effects on desertification [21]. SD is a suitable tool for this challenge. SD is a modelling methodology grounded on the theories of nonlinear dynamical systems and feedback control developed in mathematics, physics, and engineering. SD states that the main, but easily-overlooked, cause of the behavior of a complex system lies in its underlying structure of relationships, which includes feedback loops, non-linear relations, delays and decision rules. Formally, a SD model is a set of first-order ordinary differential equations that makes a stock-and-flow representation of the studied system; stock variables show the state of the system over time, and flow variables represent the processes that change the stocks [19,22]. The main advantages of SD are [23,24]: (i) it improves system understanding, and develop system thinking skills, even from the first stage of its development as causal or sketch diagrams; (ii) SD models can incorporate empirical and process-based approaches, and help integrate interdisciplinary knowledge, (iii) the SD literature provides abundant information about related methodologies; and (iv) user-friendly software platforms allow easy access for non-modeler users.

In this paper we stress the usefulnes of causal diagrams (see Sterman (2000) [22] for details). They are built by establishing the relationshipd between expannatory and explained variables. The polarity between the independent variables (x) and the dependent variables (y) can be (i) direct (+) when x and y move in the same direction, i.e., as x increases, y increases, or as x decreases, y decreases; or (ii) negative -or inverse- (−) when x and y move in the opposite direction, i.e., more x less y or vice versa. The concatenation of the causal relationships between the variables gives rise to a network of feedback loops. The sign of the feedback loops illustrates their behavior: positive feedbacks are self-reinforcing and are behind the explosive or exponential behaviour the system; negative feedback loops are self-correcting and represent the stable performance of the system. An even number of negative arrows or their absence gives rise to a positive feedback loop; an odd number of negative arrows gives rise to a negative feedback loop.

3. Results and Discussion

Causal diagrams are very useful tools for channeling associative thinking that needs to be structured into a tangible hypothesis [25]. In this process of concreteness, operational variables, i.e., those that can be measured and have a real counterpart, coexist with ambiguous or imprecise concepts. This is the case of Figure 1A, where we show some of the relationships established in the exploitation of groundwater resources in NW China. As we can see, 'Climate change' is a concept that allows us to reflect the fact that snowmelt inputs are going to decrease. As the model becomes more concrete, we will have several options to make this idea fully functional. On the one hand, we will be able to develop a whole climate model that explains the dynamics of this snowmelt. On the other hand, we can implement different climate change scenarios that are reflected in different snowmelt volumes.

The main idea that this diagram wants to convey is that feedback loops emerge from the various links between variables, which have different types of behavior associated with them. In this case, the loop is negative and has a stabilizing behavior. The water reserve will tend towards an equilibrium (which may be zero) whose value depends on various circumstances. For example, as the water table is deeper, the cost of pumping is higher and therefore discourages activity [26]. To what extent it discourages it will depend on the profitability per cubic meter, the cost of energy or the opportunity cost. It is also relevant to consider that the value of this balance is not irrelevant. When certain thresholds are crossed, processes such as aquifer subsidence, marine intrusion or desiccation of surrounding systems can be triggered [27]. Note that the stabilization of the water reserve is associated with another equilibrium, that of the irrigated area.

In complex systems, such as socioecological systems, different types of loops coexist. In Figure 1B we show a positive one, which results in an exponential growth (or decay) of the variables (typical behavior of the Anthropocene [28]). Indeed, as the profitability of a certain type of crop increases, in this case cash-crops, and the other alternatives are very unprofitable (i.e., low opportunity cost), more and more farmers opt for this alternative, which leads to an increase in the irrigated area. This leads to more profits and new farmland, leading to exponential growth in cash crop area. As it is easy to understand, this exponential behavior, towards infinity, cannot be sustained over time, but it allows us to see that, in isolation, there are parts of the system that for a time behave in a threatening way, putting the sustainability of the whole system at risk.

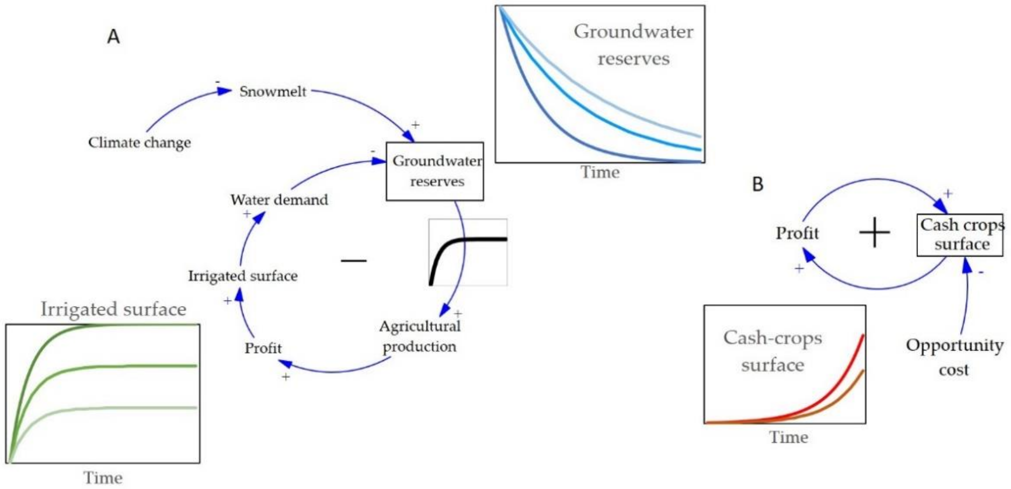

Figure 1. Causal diagrams to illustrate some of the elements of the oases dynamics in NW China. (**A**) Stabilizing behavior associated with negative feedback loops; non-linear relationship between water endowment and agricultural productivity. (**B**) Explosive behavior of a positive feedback loop.

In addition to holistically understanding this structure, SD has specific tools to highlight the delays between cause and effect (e.g., farmers decision-making time [29]), and the nonlinear nature of many of the system relationships (e.g., water productivity is not linear, but starts from zero, grows first exponentially and then linearly, and then saturates, reaching a maximum). These considerations, which lead us to more elaborate phases of the SD model, are what explain the counter-intuitive nature of the system in the face of certain solutions that try to alleviate water scarcity. Thus, for example, improving the efficiency of irrigation systems often leads to higher water consumption [30,31].

4. Conclusions

The dynamic behavior of a system depends on what kind of loops drive it. When it is a positive one it tends to behave more abruptly, while if negative ones dominate, it tends to stabilize. Therefore, understanding how these loops arise, how they are activated and how they interact, gives us clues about the sustainability or collapse (i.e., desertification) of a given system. In this sense, SD is an exploratory rather than a predictive tool. That is, the interesting thing is to qualitatively interpret outputs that respond to different what if questions that are processed by differential equations (i.e., the SD model, a quantitative method).

The power of SD lies in the fact that it is easy for people who had no previous experience in conceptualizing complex problems, such as the search for sustainable development. The confrontation between the need to create wealth and well-being, and to maintain the stock of natural resources that provide a series of fundamental services for nature to continue to function requires holistic tools in which various stakeholders, academics or decision makers participate. In a short time, causal diagrams conceptualizing this debate are put up, highlighting the trade-offs, contradictions and multiple points of view of the participants. With a little more effort, these diagrams translate the discussion into models that can be simulated so that very simple experiments with counterfactual situations can be implemented to analyze what would have happened under various scenarios (e.g., climate and land-use change).

This approach fits very well with the implementation of LDN, which should be based on land-planning and governance. What LDN aims to do is to channel existing plans, so that there are no contradictions or overlaps, and the impact of the various economic activities is counterbalanced by restoring measures. The results should lead us to a neutral human footprint, allowing the coexistence of human societies and nature.

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