THEORIES ON PROGRESSIVE DESICCATION AND DESERTIFICATION: REASSESSING THE DROUGHT HAZARD

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ABSTRACT

Processes that determine the drought hazard for the people living in arid environments have been for some time the subject of research. Recently, new theories and hypotheses popularised under the heading of ‘desertification’ have emerged that offer a number of differing interpretations of the nature of the problem. A reassessment of current knowledge on the drought hazard is provided to show that theories on desertification are in large part hybrids of those widely studied in geographical climatology and natural hazards research. Evaluation is centred on the meaning of desertification and the extent to which it is caused by changing climate, climate variability or misuse of the land. Specific examples are drawn from the Sahelian zone of Africa, the world’s casebook on drought and desertification.

INTRODUCTION

Human and physical processes that determine the drought hazard for people living in arid environments have been for some considerable time the subject of a large amount of research (for example: Burton and Hewitt 1974; Mabbutt 1978; Hare 1983; Heathcote 1983; Hewitt 1983; de Freitas 1989; Swearingen 1992). Relatively recently, however, heightened environmental consciousness spurred on by increasing awareness of the global scale of many environmental issues and widespread media coverage of the horror of suffering from drought induced malnutrition and famine particularly in Africa has spawned new theories and hypotheses popularised under the heading of “desertification”.

Desertification is commonly defined in very general terms as the effects of progressive desiccation in arid or dryland environments associated with human use of the land. Because the links between people and environmental processes are complex, there have been a variety of interpretations of the nature of the problem (Glantz 1977; Glantz and Orlovsky 1987). From this, a growing debate has emerged over the confusion between the definition of desertification caused by human actions and the impacts of naturally occurring drought. There is scepticism about the adequacy of the scientific basis for desertification and a growing awareness of the uncertainty and confusion on the extent to which desertification is a real process (Thomas 1993; Thomas and Middleton 1994).

With the above in mind, this paper reassesses current knowledge on the drought hazard with a view to showing that theories on desertification are in large part hybrids of those widely studied in geographical climatology and natural hazards research in geography. Specific examples are drawn from the Sahelian zone of Africa.

CONCEPTS AND DEFINITIONS

Drought, desiccation and desertification are key terms used in discussions of dryland environments, the meanings of which have often been misused, confused or misunderstood. Drought has many detailed definitions but, in general climatic terms, drought is said to occur when rainfall over a given period is substantially below the mean.
It is a decrease in precipitation, the effects of which may be seen in diminishing water supplies for domestic and industrial users and shortfalls in meeting water needs of rainfed agricultural systems. Desiccation is a process of drying resulting from prolonged drought.

Defining desertification is more difficult. According to Verstraete (1986), who wrote an entire article on definitions of the word, it has many meanings, some of them contradictory, most of them ambiguous. Desertification is best thought of as a complex process that results in "land degradation in arid, semiarid and dry-subhumid areas caused by adverse human impact" (UNEP 1992). Land degradation can itself be defined in several ways, but the essential meaning is reduction or destruction of biological potential resulting from the loss of soil or detrimental changes within the soil.

Drought has often been closely associated with desertification. The impact of drought on society may be in some cases inextricably linked to feedback processes between the atmosphere and the land surface as modified and used by the very population that is at risk. A result of this can be desertification. One view is that the initiative in the hazard lies with nature and therefore the potential for disaster, or potential impact intensity on population, is broadly set by natural forces (de Freitas 1989). A theoretical reference state is depicted schematically in Figure 1(a). It shows that the impact on society of physical events of variable magnitude, in the present case climate, depends on the vulnerability of the society to that variable outside of a zone of insensitivity to significant damage. Impact and damage depends, therefore, as much on the vulnerability of the society as it does on the magnitude of the physical event itself.

Figure 2 provides a conceptual framework for a discussion of the drought hazard in the Sahel. It traces linkages between the climatic context of drought, human response to the hazard, environmental degradation and demographic impact that collectively affect feedback processes that ultimately modify both the vulnerability and susceptibility of the population to drought.

**PROLONGED DROUGHT AND DESICCATION**

During this century, great droughts occurred in the Sahel in 1910-14, 1940-44 and, most recently, since 1968. Because the period 1968-1974 was so dry it became known as 'the Sahelian drought' (Bunting et al 1976). But it is in reality part of a two decade long fluctuation of rainfall over all of sub-Saharan Africa. It is now clear that the Sahelian drought has persisted from 1968, exhibiting a greater degree of persistence than any other recent drought anywhere in the world (Lamb 1983; Dennett et al 1985; Nicholson and Palao 1993). The climatological record shows (Figure 3) that desiccation of the Sahel began in the late 1950’s preceded by a ten year period when rainfall was well above normal. The end of the colonial period came just as the deterioration in climate was beginning and many countries in this part of Africa were in the throes of settling into recently acquired independence. According to Hare (1983), the decade of relatively high rainfall may have misled African statesmen into believing that lasting change had occurred.

Wherever relatively long rainfall records exist, the data show that drought is part of the normal climate of semi-arid areas. This is not surprising since rainfall in these regions is highly variable in time and space. However, unlike rainfall regimes in semi-arid areas of the globe generally, Nicholson (1980, 1981) has shown that Sahelian droughts display remarkable spatial coherence in that droughts often occur over the whole sub-Saharan belt simultaneously. This increases the areal extent of the damage and the impact potential for individual countries as well as the region as a whole.

**ROLE OF POPULATION**

In contemporary societies of the developing countries of Africa the effects of drought seem to be repetitious, probably because the effects of climatic variability are aggravated by rising population (Fig. 1b) and the absence, or reduced scale, of demographic responses that in earlier times served to greatly reduce the size of the population over the short term and suppress population recovery rates. There is also the added effect of human induced feedback processes that accentuate and even perpetuate drought phases. Since most of the non urban population engages in subsistence
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(a) Stable climate, population and human use system.

(b) Stable climate, increasing population and environmental stress.

(c) Stable population, changing climate: decreasing precipitation.

Figure 1: Hazard thresholds in relation to precipitation in the Sahel for three different scenarios: a) dynamic equilibrium of climate, population and human use of the environment; b) stable climate with increased stress on the environment from modern farming methods, overgrazing, depletion of vegetation for fuel, etc; and c) stable population along with climate change towards drier conditions. The shaded area shows a zone where damage from variation in precipitation is negligible. Figure 1(a) is adapted from Burton and Hewitt (1974) and Heathcote (1985).
Drought Hazard

Figure 2: A conceptual framework for the drought hazard in the Sahel, showing linkages between the climatic context of drought, environmental degradation, demographic response and vulnerability to the hazard.
farming and herding, the amount of rainfall determines the carrying capacity of the land. Desertification sets in when the number of people and livestock exceed the carrying capacity. In pre-colonial Africa, the number of grazing livestock and the size of the area cultivated increased with rainfall. As a dry cycle began, overgrazing and over cultivation resulted in severe environmental stress and degradation. Carrying capacity decreased and population declined accordingly as people either died or moved away (Figure 4).

In modern times, on the other hand, when carrying capacity began to decline, aid in the form of medicine, food and shelter suppressed the death rate, morbidity and the need for outmigration. The continued presence of large numbers of people might even reduce carrying capacity still further. A larger and more resilient population remained providing an elevated base from which increased growth could continue when rainfall temporarily increased again. In any event, the result is an even larger population than before. Stress on the land is such that plant cover is destroyed beyond the minimum required for the prevention of severe soil erosion (Abel and Blaikie 1989). The more fertile top soil is removed, less soil remains and therefore less moisture is retained. The soil dries out, soil temperatures increase further speeding drying and collapse of the system.

More specifically, stress on the land results from overgrazing, overcultivation and deforestation, each of which is directly related to population. Deforestation, or more precisely in this context, the removal of woody vegetation, results from the growing population’s use of wood for fuel. For example, in Niamey, the capital of Niger, 90 per cent of the people cooked with wood or charcoal (Tinker 1983). High oil prices discourage the use of kerosene which was seen as an alternative 20 years ago. According to Talbot (1986), fuelwood provides an energy source for 80 per cent of the African population.

In the developing countries of Africa, rangelands comprise over half the land area and support a large human population that is dependent, in one way or another, on grazing livestock (Talbot 1986). Overgrazing of these rangelands, the effects of which include the compaction of soil and trampling of vegetation, results from five main factors. First, population growth has meant an increase in the number of nomadic herdsmen and thus more animals. Second, better veterinary care and assistance provided by government agencies in reducing livestock diseases have resulted in lower animal mortality. Third, widespread drilling of wells has allowed more animals to be watered than the land can support in periods of drought. Fourth, many nomads have moved to the major towns where they hold lucrative government jobs. According to Tinker (1983), they often invest this money in animals in their family’s herd. Fifth, population growth in the agricultural zone has led to pressure for more land. There is a decrease in the area available for grazing as agriculturalists steadily encroach on the traditional grazing lands to farm soil that is too arid to be permanently cropped.

These are not the sole cause of desertification, but they produce land that, when drought occurs loses the capacity to protect itself and therefore the potential to
recover when the rains return. Moreover, it is an important part of the chain of processes in the system that feeds back on itself, reaffecting vulnerability of the population and, ultimately, the future drought hazard or damage potential. In wet years there is expansion and intensification of grazing and cultivation of land that is otherwise marginal. During the next relatively dry year there is an excessive demand on water stored in the soil. The soil dries and becomes susceptible to wind erosion and eventually blows away. Even if the rains were to return, what soil remains is washed away by sheet erosion and gullying. Most important, if such changes affect a large area, positive feedback processes to which

Figure 4: Relationships between rainfall, population and environmental stress in the Sahel given: a) traditional subsistence farming and land use; and b) modern agriculture with external aid and support systems (adapted from Oliver and Hidore 1984).
localised climate is highly sensitive are set in motion, which accentuate the existing anomalies in climate.

In the context of Malthusian theory, as a population exceeds its resource base during drought it is reduced in size by increased mortality due to famine. Released from stress when the rains return, the population will again grow at an increasing rate until the next drought. But mortality rates in the Sahel have been suppressed by large scale and well organized food and medical aid. For example, as early as 1980 there were 400 relief agencies in this part of Africa (Watkins and Menken 1985).

Migration has been one of the most important ways traditionally in which people respond to the drought hazard in that it enabled large numbers to survive. In the Sahel, very large numbers of people moved from the north, southward (Caldwell 1975) where conditions were initially better. The effect was a spreading of heavy exploitation of the land from the arid core along with the positive feedback mechanisms resulting from environmental stress and degradation.

From the evidence, it seems that drought in the Sahel does not have a pronounced effect on population stability (Caldwell 1975). Classic Malthusian conditions whereby a population is reduced in size by a crisis does not occur. Population growth continues as does stress on the environment so that with time there is increased sensitivity and vulnerability to periods of high rainfall variability (Figure 1b). During the next stage the amplifying effects of drought and climate would lead to severe degradation of environmental resources resulting in desertification. Developing countries are especially vulnerable, not only because they have fast-growing population, but also little money for preventative measures to lessen the impact such as would be required for land use management reform, irrigation systems and the like.

THE CLIMATE CONTEXT

It is not uncommon to consider climate to be the major contributor to desertification processes. A key factor in the role of climate is stability of air. When the atmosphere is stable, upward motion of air is suppressed. Even in humid airstreams, rainfall will not occur unless stability is overcome. It is the widespread, persistent atmospheric subsidence associated with the subtropical high pressure belts that accounts for most of the large areas of arid and semiarid climates of the world, including those of northern Africa. These high pressure belts migrate poleward in summer and equatorward in winter.

Rain is brought to the Sahel by the African summer monsoon. It is an annual cycle dominated by the northward advance of warm, rain-bearing oceanic air over the land affecting an area between the sea and intertropical convergence zone (ITCZ) in the north. The Sahel is at the northern edge of this area which experiences drought when the summer monsoon does not reach far enough north. The ITCZ is roughly the equivalent of the thermal equator or low pressure boundary zone that migrates seasonally along with the low latitude high pressure cells that cause the world's great deserts and the Westerly Wind system that controls the mid-latitude climate of Europe (Figure 5). During the summer, net radiation at the surface is greater in the Northern than in the Southern Hemisphere. This causes the large atmospheric pressure systems to migrate to their most northerly location. Movement depends largely on solar energy available for driving the pressure systems and winds. Should the migration of the ITCZ advance only a few degrees of latitude less than normal, large areas of the Sahel experience a great reduction in rain (Motha et al 1980; Nicholson and Chervin 1983). In recent years the northward movement of the rain-bearing air has been less than normal and, in effect, the dry Sahara climate has been moving south. The possible reasons for this have been critically reviewed in the literature (Schneider 1976; Hare 1976, 1977, 1983, 1984; Druyan 1989). From these, seven 'theories' have been identified and are outlined below.

The first is the status quo theory which is the most basic. It holds that the failure of the summer monsoon that brings drought is a normally recurring problem in the Sahel since it is a region characterised by high variability of rainfall due to the irregular movement of the ITCZ. Recent rapid population growth and more intense agricultural land use practices that adjusted over the short-term to the good rainfall years have resulted in more serious consequences
of drought in modern times compared with that in the past (Figure 4).

The second is the climate change theory which rejects fluctuation of climate in favour of a natural shift in climate regimes. The view is that climate not only varies year by year, but is constantly changing. Moreover, it can change rapidly to a new multi-year average.

Large scale atmospheric circulation, and the Westerlies in particular, have a role in the next two theories. The Westerlies are a mid-latitude wind system that sweep in a meandering pattern around the poles (Figure 5). They are an important part of the general circulation of the atmosphere, expanding and contracting seasonally and annually in response to solar heating. Climates in many places are directly related through the behaviour of the Westerlies. The Bryson theory (Bryson 1973, 1974) suggests that a strengthening of the thermal gradient between the equator and North Pole has led to increased vigour of circulation in the Westerly wind belt which has pushed the summer monsoon and ITCZ towards the equator, away from the Sahel.

In contrast, the Winstanley theory supports the view that a change in atmospheric circulation has occurred involving a southward shift of the Westerlies,
the ITCZ and, consequently, the northern limit of the summer monsoon (Winstanley 1973; Winstanley, Emmett and Winstanley 1976, cited in Schneider 1976). But the reason is given as a weakening in mid-latitude Westerly wind circulation accompanied by a reduction in the volume of rain-bearing tropical air that moves northwards towards the Sahel in summer Schupelius 1976; Kanamitsu and Krishnamurti 1978; Lamb 1980). The cause of this is not clear, but it is possible it may be related to solar heating.

The Dust Desertification theory asserts that overgrazing of the land by livestock leads to loss of vegetation resulting in bare soil being exposed to wind erosion (Bryson 1973; Bryson and Murray 1977). Large quantities of windblown dust and aerosols in the atmosphere reduce incoming solar radiation and heating of the land surface. It has been known for some time that very large amounts of this dust originate in the Sahara and its surrounds and it occurs in such large quantities in the atmosphere that it can affect visibility as far west as the Caribbean. This dust in the atmosphere reduces incoming solar radiation and heating of the land surface which in turn leads to a reduction in convective activity and rainfall brought about by rising warm air. This leads to a reduction in convective activity and rainfall brought about by the rising warm air. It is also possible that dust may directly affect precipitation by making available too many condensation nuclei which collectively compete for the water in clouds. The resulting water droplets are too small for coalescence and raindrop formation to occur. The smaller droplets will not collide or merge because, as they approach one another, they are forced apart by the air flow between them.

The Charney theory also cites overgrazing as a catalyst. The mechanism in this case is higher reflectivity of the bare or sparsely covered terrain compared with a vegetated surface (Otterman 1974; Charney 1976; Charney, Stone and Quirk 1975; Laval 1986). The additional reflection of solar energy results in a radiation deficit and associated cooling. This in turn leads to subsidence of air which expands as it descends, drying and warming in the process and inhibiting cloud formation. Thus, the increased reflectivity of the terrain causes the effects of the subtropical high pressure belt to extend outward from the Sahara in the north further into the Sahel leading to drying. The dry conditions result in a further loss of vegetation causing increased reflectivity and subsidence of dry air even further to the south, and so on in a cycle of positive feedbacks.

The Schnell theory relates directly to the well established Bergeron-Findeisen theory of precipitation formation which states that certain, relatively rare, particles in the air promote the freezing of supercooled water droplets of which (cold) clouds are comprised. The most efficient of these ice forming nuclei are believed to be of botanical origin. Once these ice crystals have formed in clouds they grow at the expense of the surrounding supercooled water droplets. The rate of ice crystal growth increases by collision with supercooled water droplets until the particle is too large to be suspended by air currents (de Freitas and Woolmington 1980). As ice particles fall through the lower part of the air they may grow further by collision. As ice crystals grow they become unstable and pieces break off to form more nuclei. The process ends as particles emerge from the base of the cloud and melt as they move through the air, falling to the surface as rain. Thus, a very specific triggering process is required to set in motion a self-amplifying feedback mechanism resulting in rainfall. According to Schnell (1975), when efficient ice nuclei become scarce precipitation is reduced. With less rain there is less vegetation. Grazing animals have to compete for dwindling amounts of vegetation which is further reduced as a result. This in turn reduces even more the supply of biological ice forming nuclei in a self-perpetuating, self-amplifying, positive feedback process.

It is likely that a combination of factors relating both to aspects of natural climatic fluctuations due to oscillations of general atmospheric circulation and feedback effects of land use practices on atmospheric processes provide an explanation of processes operating in Africa. Nicholson (1981, 1983), for example, has suggested that the drought is not caused by large scale differences in the position of the ITCZ, but rather by factors that determine atmospheric stability at, or immediately behind, the ITCZ. The effect is that a decrease in rainfall is enhanced by processes resulting from environmental stress caused by human populations. These trigger feedback processes.
of land-atmosphere interaction that reinforce dryness. The net result is an expansion of desert margins or, at the very least, conditions under which a 'natural' drought prolongs itself.

CONCLUSION

Conceptual frameworks developed in natural hazards research can provide a backdrop for identifying and assessing the potential for and susceptibility to drought-related disasters in dry sub-humid, semi-arid and arid regions. They enable identification of human as well as climatically induced changes in the environment. The risk to human communities from prolonged dry periods is viewed in terms of socioeconomic, cultural and environmental factors involved and their links with population. Patterns of causality can be traced that highlight the ways in which societies respond to climate variability as well as the way in which this response may affect vulnerability to drought. As in the case of the Sahel, there is reason to believe that the impact of drought on the population may be inextricably linked to feedback processes between the atmosphere and the land surface as modified and used by the very population that is at risk. It is argued that the initiative in the hazard lies with nature. The potential for disaster, or potential impact intensity on population, is broadly set by natural forces, whereas the impact on society of drought-events of variable magnitude depends on the vulnerability of the society to that variable. A distinction can be made between damaging environmental changes (mainly soil degradation) and natural cycles of variability of rainfall. It is possible to trace linkages between the climatic context of drought, human response to the hazard and environmental degradation that collectively affect feedback processes that ultimately modify both the vulnerability and susceptibility of the population to drought and desertification.

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