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Ya Ding
University of Nebraska, Lincoln, yding2@unl.edu

Michael J. Hayes
University of Nebraska at Lincoln, mhayes2@unl.edu

Melissa Widhalm
University of Nebraska at Lincoln, mwidhalm3@unl.edu

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By Ya Ding, Michael J. Hayes, and Melissa Widhalm

Ya Ding is a post-doc researcher with the National Drought Mitigation Center at the University of Nebraska. Michael J. Hayes is an associate professor/director of the National Drought Mitigation Center at the University of Nebraska. Melissa Widhalm is a climatologist with the National Drought Mitigation Center at the University of Nebraska.

Correspondence: Ya Ding, National Drought Mitigation Center, 820 Hardin Hall, University of Nebraska-Lincoln, Lincoln, NE 68583-0988. Email: yding2@unl.edu

Abstract

A comprehensive assessment of drought economic impacts provides critical information to rational decisions supporting drought mitigation policies and programs. The objective of this paper is to increase the understanding of the full scope of drought economic impacts and the associated quantitative assessment methodologies. To accomplish this, the paper reviews the literature of drought economic impact studies in both agricultural and non-agricultural sectors, summarizes the methods and data employed, compares the various results, and investigates the problems and limitations of previous studies. The paper concludes with a discussion of the challenges and directions of future improvement on drought economic impact assessment.

Key words: drought, economic impact, estimation

Introduction

Growing public awareness of the issue of global climate change has raised enormous concerns regarding its potential impacts and consequences. Although there are inconclusive findings on the specific impacts of climate change on regional water resources, many scientists have suggested that climate change is likely to increase the frequency and intensity of extreme climate events such as drought (IPCC 2007). In addition to the risk to future water supplies brought on by climate change, population growth, urban expansion and requirements for environmental protection have been stressing local water supplies in many places, exacerbating competition for already scarce water resources.

The integration of these issues poses great challenges for existing drought policies, which have been largely focused on short-term responsive actions rather than proactive planning and mitigation strategies. Although effective responsive actions are important for soothing short-term disturbances and providing emergency supplies to maintain basic functioning of industries and markets, they are incapable of increasing long-term social-economic resilience to future drought impacts. It is generally agreed that mitigation and preparedness are keys to reducing future drought risks; however, government officials are often reluctant to allocate money and resources to mitigation because of limited information on the costs and benefits of drought mitigation programs. In fact, a report of the Council of Governors' Policy Advisors (Brenner 1997) identified the "lack of information" as a major obstacle in adopting mitigation strategies.

Cost-benefit analysis (CBA) has been widely employed to evaluate economic feasibility of public projects and policies (U.S. Water Resources Council 1983, Hanley and Spash 1993, Griffin 2007). Projects are considered economically acceptable if summed benefits exceed summed costs. The costs of a mitigation project are usually up-front; while the benefits of the project are more uncertain and harder to predict. We are interested in the methodologies of computing the costs of disasters because the benefits of mitigation programs can be approximated by using the estimated costs of the disaster that would be otherwise avoided by the mitigation programs. Therefore, in order to understand the monetary benefits of drought mitigation programs, quantification of the economic impacts of drought need to be available.

In spite of the importance of accessing drought economic impacts, few studies have been done in a consistent or systematic manner. Inconsistent mixes of production losses, indemnity payments, and relief costs are often quoted by the media and misused by decision makers. In addition, many analyses have been focused on agricultural losses only and do not capture the broad range of impacts resulting from drought.

The objective of this review paper is to provide useful information for members of the weather community and policy makers to help them understand the full scope of drought economic impacts and assessment methodologies, and to help determine the feasibility of future drought mitigation programs. To accomplish this, the paper reviews the existing literature, summarizes the methods and major findings, investigates the problems and limitations of previous studies, and discusses the challenges and future directions of developing consistent and systematic tools for assessing drought economic impacts.

Understanding Drought and Drought Impacts

Drought can occur in any climate of the world. In general, it is known as a climate-related condition relative to what is perceived as 'normal'. Because normal precipitation and water use expectations vary, the specific definition of drought is more a matter of where the water comes from and how it is being used. Unlike other natural hazards such as floods, hurricanes, tornadoes, and earthquakes, which occur over finite periods of time and result in visually obvious damage, drought develops slowly and quietly, lacking highly visible and structural impacts. Developing drought conditions often go unnoticed until precipitation shortages become severe and impacts begin to occur. The slow pace and long duration of drought typically makes it difficult to quantify the overall economic impacts.

The impacts from natural hazards, including drought, can be both direct and indirect. Direct and indirect effects are sometimes referred to as primary and secondary (or higher-order) effects in the literature. Identifying an adequate definition for direct and indirect impacts is important for economic impact assessments because the bounds set by such definitions dictate the scope of impacts that may or may not be included. However, one challenge is that a clear and consistent classification of these two types of effects is lacking. Van der Veen (2004) reviewed different cost concepts used in the economic literature of disasters. In the manuals of Flood Hazard Research Center Parker et al. (1987), direct costs were limited to loss of land, houses and machinery; while indirect costs are related to business interruption as well as backward and forward multiplier effects in the economy. Similarly, according to the definition given in a study by the National Academy of Sciences (1999), direct impacts result "from the physical destruction of buildings, crops, and natural resources", while indirect impacts are "the consequences of that destruction, such as temporary unemployment and business interruption" (National Academy of Sciences 1999, p. 5). Since direct impacts are often solely used in the estimation of economic losses, using this definition, only crop or pasture losses are counted as direct drought impacts. Large-scale business interruption losses would all be excluded. Certainly, it is not practical to use this definition in estimating the economic impacts of drought.

Cochrane (1997) and Rose (2004) proposed to extend the definition of direct costs to include not only the physical damages but also the consequences such as business interruption and unemployment. They redefined indirect costs as arising from interactions and transactions between economic industries and sectors. Since drought cause less visible and obvious physical damage, but incurs considerable losses in terms of business interruption and unemployment; therefore, we recommend using this definition for drought impact assessment. We will discuss in more details about indirect or secondary impacts of drought in the next section.

Economic Impacts of Drought

Drought-induced water deficiency affects production, sales, and business operations in a variety of industries. In this paper, these effects are referred to as the direct economic impacts of drought; while, indirect economic impacts of drought stem from the interactions and transactions among industries and sectors. Drought also causes environmental and social impacts, and results in non-market losses. An overview of drought economic impacts is supplied in Figure 1.

Agricultural Sector

Drought impacts are most eye-catching in the agricultural sector. Dried crops, abandoned farmland, and withered and yellow pastureland are the common signs of drought. Prolonged soil moisture deficits due to drought cause damage to crops and pastures. Crop failures and pasture losses are the primary direct economic impact of drought within the agricultural sector. Drought-induced production losses cause negative supply shocks, but the amount of incurred economic impacts and distribution of losses depends on the market structure and interaction between the supply and demand of agricultural products.

Drought-induced losses are not completely borne by farmers; instead, a portion of the losses are passed on to consumers through increased prices. The higher the price increases, the more losses will be passed on to consumers. It is even possible that farmers are better off from the drought impacts, given that the price increases by a higher percentage than the supply decreases. Additionally, farmers purchasing crop insurance will get part of their losses compensated by insurance companies, and some eligible farmers may receive direct disaster aid from the government. The ultimate losses borne by farmers could be very different from the actual impacts caused by drought. It is a common mistake to equate farmers' income losses with the economic impacts of drought. Therefore, it is important to quantify overall drought impacts as well as identify the losses borne by different stakeholders.

The economic impacts of drought are complicated because drought also creates winners. Drought-induced higher prices would attract goods from other regions to flow into the local market, which helps smooth the supply shortage and limits the price increase. In this case, producers outside the drought-stricken area benefit from favorable prices. Therefore, it is important to establish the geographic coverage or the accounting stance when assessing the drought impacts. Local drought impacts might be cancelled out when evaluated at regional or national level. Zero-sum transfers of losses or gains should be excluded from impact assessment (Griffin 1998). Another important issue is that drought causes long-term impacts on perennial crops and livestock productions. The negative impacts in these cases might linger for multiple years. Considering these lagged effects of drought, it is important to set a time frame when assessing the economic impacts of drought.

Non-agricultural Sectors

Drought also causes significant economic impacts in non-agricultural sectors through its effects on water supplies including streamflows, reservoirs, wetlands, and groundwater. These non-agricultural sectors include, but are not limited to, tourism and recreation, public utilities, horticulture and landscaping services, navigation and other industries/businesses that have significant water consumption.

Public water supply systems are designed to deliver clean water to the public on a continuous basis. If their water sources are from reservoirs or groundwater aquifers, they would not be subject to effects of short-term precipitation variations. However, the occurrence of severe and sustained droughts that deplete water storage can still cause water scarcity, deteriorated water quality, and even interruptions of supply. To manage water shortages, water authorities can adopt adjustments that reduce water demand or adjustments that increase water supply. Demand-side measures include but are not limited to voluntary and mandatory use restrictions, price changes, conservation education programs, and investment in water-saving equipment and appliances. Supply-side measures can include finding alternative water sources, providing emergency supplies (drilling new wells, hauling in water), and recycling water. The losses caused by drought include: households' welfare losses due to restricted water use and deteriorated water quality; lost production or sales for industries and businesses due to forced slowdown or shutdown; costs of emergency supplies; revenue losses and increased monitoring and treatment costs for water suppliers.

In the tourism and recreation sector, since many activities are water-related, droughts can bring critical losses to businesses in drought-stricken areas. Drought impacts exist for both winter and summer recreational activities. In winter, a lack of precipitation in the form of snow affects the business of ski resorts. Although many resorts could lessen the drought impact temporarily with snowmaking, it incurs additional costs and competition over water rights. Additionally, winter drought affects the level of snow pack stored at higher elevations, which in turn affects snowmelt and streamflows during the following spring. Reduced streamflows might result in fewer visits and a shorter rafting season. Other summer recreational activities, like fishing and boating, can be affected by drought as well, especially a multi-year drought that depletes water in lakes and reservoirs.

Nursery and landscaping service businesses also face big losses from drought. Droughts cause damage to nursery crops and add additional costs of watering newly installed plants and replacing dead ones. Plant sales may decline because of increased plant mortality and water use restrictions triggered by drought. During the historic drought in the southeast United States in 2007, many businesses were forced to close locations, lay off employees, or even file for bankruptcy. The Georgia-based nursery chain Pike Nursery filed for bankruptcy protection because of drought-induced financial difficulties (Bond 2007).

Other sectors subject to drought impacts include navigation and construction. Because the factors influencing business operations are numerous, drought impacts in non-agricultural sectors are uncertain and vary across time and location. It is important to consider the macroeconomic influences and local characteristics when estimating these impacts.

Secondary Effects

The secondary impacts of drought, as well as other natural disasters, are attributed to the interactions and transactions among industries and sectors. Outputs from one industry/sector become inputs into other industries/sectors. Therefore, the direct economic impacts on an individual industry would spread through the upstream or downstream linkages to other industries, causing secondary impacts. For example, farmers with crop losses will reduce their supplies to the downstream industries, such as food processors and ethanol plants. These consumers would have to bid a higher price for the inputs or otherwise reduce their production for the lack of inputs. In turn, their downstream customers may be forced to do the same. Such types of effects are called downstream or forward effects. On the contrary, farmers may reduce their input requirements like fertilizer from the upstream suppliers, which can cause upstream, or backward, effects. The upstream and downstream effects together are referred to as indirect effects. In addition, any income reduction caused by a disaster would force consumers to diminish expenditures, and thus generate another round of impacts. Such impacts are usually referred to as induced effects in the literature, and they are also part of the secondary effects.

The most popular approach used to estimate the secondary effects from an exogenous change such as drought is the Input-Output (I-O) model. The I-O model is based on the interdependencies between industries and sectors within an economic region. The fundamental idea is that the output of a product produced by one sector is equivalent to the amount of that product purchased by all the users. IMPLAN is a commonly accepted software package for applying I-O analysis, and it was first developed by the U.S. Forest Service and is now managed by the Minnesota IMPLAN Group (available at http://www.implan.com). I-O model has shortcomings, with the major ones being the assumption of no input substitution, no price effects, and no constraints on resources. These assumptions might result in overestimates of the secondary impacts[1].

Another approach used to estimate the secondary effects is the Computable General Equilibrium (CGE) Model, which is a more advanced extension to the I-O model. This model is more sophisticated and flexible. It capitalizes on the advantages of the I-O model and overcomes many of its limitations (Shoven and Whalley 1992, Rose 1995).

[1] See Leontief (1986) for a comprehensive introduction to Input-Output models.

For example, it allows for input substitution, incorporation of price effects, and inclusion of resource constraints. However, its implementation is more difficult because it requires a wider range of data and a higher level of aggregation of sectors.

Non-market drought impacts

Drought impacts were usually grouped into three principal areas: economic, environmental, and social (Wilhite and Glantz 1985, Wilhite 1993). In the past sections, we have discussed drought impacts in a range of sectors and industries, as well as secondary effects of drought through interactions among economic sectors. From economic perspective, environmental and social impacts can also lead to economic consequences. In other words, any welfare changes experienced by human beings should be counted into the measures of drought economic impacts. For example, if drought causes damages to the habitat of endangered species, then the welfare of people who care about these species would be harmed and therefore should be counted as a part of drought incurred losses. Similarly, if drought causes health problems, like stress and anxiety to people, their lost welfare should also be counted as a part of drought incurred losses. Economists and other social scientists have developed various methodologies and techniques to evaluate non-market values. The three most commonly used ones are: travel cost, hedonic pricing, and contingent evaluation (Freeman 1993, Wilson and Carpenter 1999, Champ *et al*., 2003).

Although non-market losses could be considerable, quantification of such losses are rarely included into drought impact assessment or other disaster loss calculation. “Disaster losses are almost exclusively limited to impacts measured by market values,” and “Non-market losses are never estimated.” (Cochrane 2004, p.290). Possible reasons that impede the estimation of non-market impacts are: non-market evaluation methods are difficult, expensive and time-consuming; researchers are required to have a high level of economic knowledge and specialized expertise in data collection and modeling; some non-market impacts are incommensurable or intangible.

Empirical Studies of Drought Impacts

Although drought impacts exist in a variety of sectors, most impact studies are focused on the agricultural sector or sub-sectors, for three main reasons. First, agriculture activities are highly sensitive to weather variability. Drought impacts on crops and pastures are direct and immediately observed. Second, data in the agricultural sector are easier to obtain than in other sectors. Many studies that we reviewed employed the “with and without” approach to estimate drought losses. This approach compares the values of economic variables under drought with those under normal weather conditions. Most commonly, the historical average values were assumed to be the normal values, and the data requirement of historical records is largely satisfied by USDA’s National Agricultural Statistics Service (NASS). NASS maintains comprehensive databases of land use, farm income, crop production, livestock inventory, and commodity prices, in a timely and consistent manner. For other sectors (e.g., tourism), although some historic records or statistics are available at regional or sub-regional levels, the definitions of variables, collection procedures, accounting stances, and data update processes are not consistent nationwide. Such data limitations make comparisons across time and location difficult for these sectors. Third, monetary estimates of drought losses are often collected in the drought-stricken areas seeking federal disaster aid. Historically, most relief programs have been available for agriculture only. The loss estimates are critical for the decision-making process of federal relief funds. However, such estimates are usually put together in a limited time frame, and sometimes before the drought terminates and the impacts are fully realized; therefore, the estimated figures might not be accurate and caution should be exercised when using them.

In the United States, most of the empirical drought impact assessments that have been conducted were at the state level. One representative study was conducted by Diersen et al. (2002). They examined economic impacts in South Dakota from the 2002 drought. They estimated the direct drought impacts on crop and livestock production, as well as the secondary effects on the state's economy, using an I-O model. Their original estimate of total impacts amounted to $1.8 billion. Later that year, Diersen and Taylor (2003) reexamined the drought impacts by considering the improved market conditions and direct federal aid of $100 million that was provided to the state. As a result, the estimated overall impact was revised from $1.8 billion to $1.4 billion. This is a key issue and demonstrates why estimates should be used with caution. It also illustrates that market conditions may improve because of the drought-induced supply shortage. A similar study was conducted by the Food and Agricultural Policy Research Institute at the University of Missouri. They estimated that the drought of 2002 in Missouri caused a total direct loss of $251 million in the agricultural sector (the combined crop and livestock losses reduced by USDA livestock compensation and cost share payments), and negative multiplier effects of $209 million on the state economy. Other statewide impact analyses include the 1998-2000 Georgia drought report (Georgia Department of Natural

Resources 2001), the 2005 Illinois drought report (Changnon and Knapp 2006), and the 2001-2002 Oklahoma drought report (Arndt 2002). These reports discussed drought impacts on the agricultural sector as well as other sectors (e.g., energy, commercials, and residences), but no systematic quantitative estimation methods were given.

Research on the economic losses outside the agricultural sector is limited, and most studies have been in the municipal water supply sector. Russell et al. (1970) estimated the impact of the 1962-1966 drought in Massachusetts. They obtained the majority of data through interviews with government officials, water utilities managers, and industrial/commercial leaders. The estimated drought-incurred losses included business losses and investment costs for industrial/commercial firms; revenue loss and emergency supply costs for water utilities; and well investment and sprinkler losses for domestic residents. The estimated losses were between $5 and $13 per capita, in 1970 US dollars. More recently, Garcia-Valiñas (2006) analyzed the impact of water use restrictions and water quality reductions on consumer welfare during the drought period of the early 1990s in Seville (Spain). The water demand functions were estimated for residential and industrial/commercial customers, respectively, using quarterly water bill data as well as other economic information. The welfare variations were then calculated based on the water demand functions. The average welfare losses, in 2001 Euros, were €138.3 ($124.5 in 2001 US Dollar) per user and quarter for households and €62.6 ($56.3 in 2001 US Dollar) for industrial/commercial firms. Another group of studies estimated the amount of money people are willing to pay (WTP) to increase water supply security or to avoid water use restrictions, using contingent evaluation methods (Howe and Smith 1994; Griffin and Mjelde 2000; Koss and Khawaja 2001) or choice modeling (Hensher et al. 2006). However, these studies gave various results of the WTP, partly because of the different specifications on the frequency and severity of water restrictions caused by drought.

The impact assessment of municipal drought addressed part of the losses of the horticulture and landscaping industry, but not in any thorough fashion. Hodges and Haydu (2003) investigated the drought impacts on the Florida horticulture industry during 2000. They considered the impacts of drought on both sales and purchases of horticultural products and services. Their estimates were not restricted to the nursery sector, but also encompassed retailers, landscapers, and consumers. The drought impacts were not negative for all affected sectors. Some businesses (e.g., retailers) benefited from the drought as a result of demand for replacement plants.

Drought impact studies on recreation and tourism are mostly qualitative or restricted to businesses within a local area. Schneckenburter and Aukerman (2003) analyzed the economic effects of the 2002 drought on Colorado's recreation and tourism industry, which suffered statewide, but "often takes a back seat to the interests of agriculture in terms of policy and public support". The authors provided a snapshot of the drought impacts through a series of one-on-one interviews with stakeholders. Enormous and severe drought impacts were described for state and county parks, the boating industry, the rafting industry, and the fishing industry. In another study, Leones et al. (1997) examined the impacts of streamflow depletion on rafting businesses in northern New Mexico counties. They found that the lower water levels generally had negative effects on daily visitor numbers and rafting-related expenditures, but the magnitude of the impacts depended on the characteristics of the river courses. They also analyzed the indirect impacts of the rafting industry on the regional economy through the use of an Input-Output model. The results indicated that maintaining higher-than-actual levels of summer streamflows would have generated $0.94 million more from rafting and 44 additional jobs.

Very few studies estimated drought impacts at the national level. Riebsame et al. (1991) studied the national economic impacts of the 1988 drought in United States. They looked into the impacts for several sectors, including agriculture, transportation, power generation, recreation, commerce, and industry. They estimated the total cost of the 1988 drought at $39.2 billion (in 1988 US dollars). Their estimates are often cited by government officials, although they are indeed problematic. First, federal disaster aid and crop insurance payments were included as costs of drought, which is incorrect. How federal payments should be considered depends on the scope of analysis. If the scope is Nebraska only, then federal payments would be a benefit of the drought. However, if the scope is national, the federal payments are a transfer payment to be ignored. Second, a drought-induced supply shortage drove food prices up, which increased the spending of consumers, but also raised producers' income as well. The authors considered only the consumer's losses due to higher food prices, but not producers' gains, which would result in the overestimate of drought losses. On the other hand, losses suffered by other sectors, such as public water supply, tourism, and recreation, were not included. Therefore, given these overestimates and underestimates, the question is really whether or not the Riebsame et al. estimate is reasonable and "in the ballpark," so to speak.

More recent nationwide measurements of drought impacts have been conducted in Canada and Australia. Kulshreshtha et al. (2003) estimated the economic costs of the droughts of 2001 and 2002 to the regional and national economy of Canada. The study focused on agricultural impacts of the droughts (impacts on crops, livestock, orchards, and vineyards), and secondary impacts were projected using an Input-Output model. Impacts on other sectors were reviewed and described in a qualitative manner. The direct and secondary impacts of drought on agriculture were estimated for each individual region (Canada was divided into four regions) and then summarized for the entire nation. As a whole, the lost gross domestic product (GDP) was estimated at C$3.65 billion (or $2.34 billion in 2001-2002 US dollar), and a loss of 23,777 jobs also resulted. Horridge et al. (2005) measured the impacts of the 2002-2003 droughts on Australia. To estimate the direct impacts, the authors computed productivity losses due to rainfall deficits in each individual region, and then summarized to the national level. The direct losses from drought were introduced as output shocks to The Enormous Regional Model (TERM), i.e., a Computable General Equilibrium model for Australia; and the indirect impacts at regional and national levels were projected. The results indicated that the 2002-2003 droughts caused an overall reduction of Australian GDP by 1.6%, of which 1% was directly related to agricultural sector, and the remaining 0.6% was due to multiplier effects.

Conclusion

Given the infrequent occurrence of natural hazards and the numerous factors influencing economic activities, it is a great challenge to separate the impacts of a natural disaster from other factors and quantify them. Compared to other natural disasters, drought typically has an unclear onset or ending, a large spatial coverage, and an extended duration; which all make the drought impact assessment an even more challenging task. Although difficult, understanding the economic impacts of drought is important for developing effective relief and mitigation strategies. Accurate estimates of drought impacts are needed to justify the initial investments in many mitigation activities. Better loss estimates are also helpful in facilitating allocation of drought relief to those most in need.

In this paper, previous studies on assessing economic impacts of drought were reviewed and discussed. We illustrated the underlying economic theories of drought impacts, summarized the methods and data employed in the literature, and pointed out the limitations and issues within the existing studies. The experience and lessons learned provide valuable information for future improvement of drought economic impact assessment.

Lessons Learned and Recommendations:

- Similar to federal disaster payments, most drought impact studies were ad hoc, following a specific drought disaster. Considering that drought is the most common natural disaster in the United States (14% of the country experiences severe or extreme drought at any one time), it is recommended that a national database of drought impacts, and the economic losses associated with these impacts, be developed. The Drought Impact Reporter tool hosted on the National Drought Mitigation Center's website has been designed as this database (available at http://droughtreporter.unl.edu). The Drought Impact Reporter tracks drought impact reports/stories from media, public, and a variety of federal and state networks. Currently, this tool is still under development and testing; and we expect it will provide comprehensive and timely information for researchers, planners, policy makers, and the general public.

- Many drought impact estimates were focused on short-term losses of production and income, while the lagged or dynamic impacts of drought on perennial crops and livestock cycles were less investigated.
- Different assumptions were made about normal conditions. The impact measurements were not comparable across regions. We suggest that guidelines be developed for data collection and model utilization that can be customized to accommodate local features.
- Non-market losses of drought should be considered. Even though the quantification of non-market impacts is difficult and sometimes impossible to obtain, a qualitative description need to be available.
- The economic impacts of drought are not only restricted to monetary losses or job losses. Previous studies have found that drought significantly increases the adoption of water-conserving irrigation systems and tillage practices (Carey and Zilberman 2002; Ding et al. 2009). Such voluntary mitigation activities would increase drought resilience of agricultural production in the long run.
- Last but not the least, interdisciplinary research is needed on the quantitative measurement of drought economic impacts. Economists, meteorologists, hydrologists and water managers need to work together to obtain a comprehensive assessment of economic impacts of drought.

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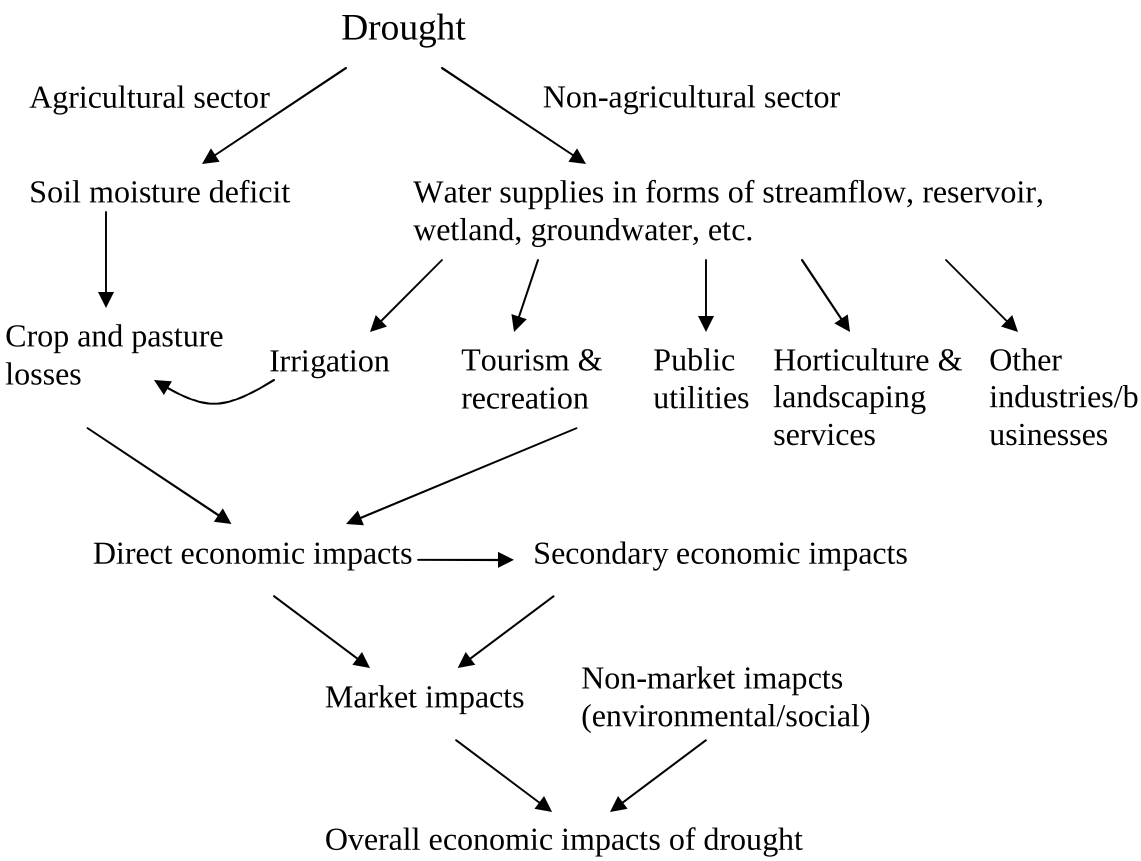

Figure 1: An overview of drought economic impacts