Integrated analysis of the impacts of climate change on food security and economic livelihoods: Application of RCPs climate scenarios

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Abstract

Small Island Developing States are some of the most vulnerable to climate stress despite their modest contribution to carbon emissions. To date little scholarly research has addressed the economic impacts of climate stress associated with abstraction from limited groundwater resources required to meet urban and agricultural requirements. Employing downscaled data on precipitation from the Representative Connection Pathway (RCPs), this work aims to develop, apply, and interpret a groundwater hydroeconomic framework for a single unconfined karst aquifer system. The framework integrates groundwater hydrology characteristics, climate scenarios, economic, land use, agronomy, and groundwater abstraction policies. It is used to assess the impacts of climate change on the performance of groundwater management policies, with special attention to groundwater sustainability, economic livelihoods, urban needs, and food security. The findings indicate that climate change will exacerbate the challenges being faced by SIDS reliant on groundwater resources. Over a period of 2018 to 2100, limiting groundwater abstraction can protect aquifer sustainability, but it would produce negative impacts on food and water consumers' welfare. However, the negativity associated with protecting the groundwater is smaller than that associated with the increasingly severe climate change RCP scenarios. The negative impact of the climate change scenarios and sustainable management would be experienced in the long run rather than the short and medium term. The results provide a framework to assess the water management and policy options for countries that are vulnerable to climate change when endowed with limited water resources such as Small Islands Developing States and Tropical Regions.

Keywords: *Climate change, groundwater demand, water tariff, abstraction policy, RCPs*

1 Introduction

Meeting the growing water demand for food production and urban use in SIDS that depend on groundwater presents an ongoing and growing challenge; especially when with the growing evidence of climate change. Both climate change and measures to mitigation its affects are likely to be associated with serious consequences on both human activities and environmental sustainability. Therefore, a better understanding of the economic impacts associated with groundwater sustainability, food security, and consumer welfare could facilitate more efficient and sustainable adaptation and mitigation measures among competing water users.

Climate change is found to reduce groundwater sustainability and groundwater recharge, due to increased temperature, rising evapotranspiration, and decreasing precipitation (Kambale et al., 2017; Melo and Wendland, 2017). That is, decreased groundwater recharge would increase the vulnerability to climate change over many region, where the decline of groundwater recharge could be higher than the decline in precipitation (Doll, 2009; Ng et al., 2010). Karst aquifers in particular are among the most vulnerable to climate change, and moreover these are some of the most difficult to estimate groundwater recharge and behavior (Jia et al., 2017; Jones and Banner, 2003). Barbados represents an example of this. These kinds of aquifers could experience higher reductions in recharge even under small variations in precipitation, making them more vulnerable to the future climate changes (Barkey and Bailey, 2017). In such cases, land use and water abstraction management could be an efficient and sustainable tool to enhance aquifer recharge and sustainability (Charlier et al., 2015; Gohar and Cashman, 2016). Climate change could also increase the vulnerability to saltwater intrusion and reduce the effective storage capacity (Chang et al., 2016).

Harmonizing water supply and demand in this environment is a major challenge, where climate change could stress groundwater supply, while growing urbanization and human activities are likely to escalate the demand for water. Factors such as demographic changes, escalating demand for food, and energy production all serve to make the projection of water demand a real challenge (Carter and Parker, 2009). Recent findings indicate that water demand met from groundwater resources is affected by several factors including population, income, tourism, and the cost of providing water. In terms of economic impacts, climate change will affect all water using sectors such as agriculture and urban areas, and countries could suffer different levels of economic losses without special mitigating actions (Tol, 2013). Climate change also stands to reduce aquifer recharge with the resulting outcome that food production could be sustained only at higher costs (Gohar and Cashman, 2015).

2 Data and method

A downscaled regional dataset on precipitation from Representative Connection Pathway (RCPs) emission scenarios (RCP2.6, RCP4.5, and RCP8.5) is integrated into a unified model incorporating groundwater hydrology, economics, and policy application to assess the economic impact of climate change on groundwater sustainability, water supplier revenue, food security, and consumers economic welfare. Water demands by climate driven scenarios are estimated for different water sectors including agricultural, household uses, tourism, cruise ship services, and commercial water use. The economic impacts of two abstraction strategies, one for protecting aquifer sustainability (*Constrained abstraction*) and another for satisfying sectoral water demand for current use (*Unconstrained abstraction*) are investigated. The framework was developed using the General Algebraic Modeling System (GAMS) software and applied for Barbados as an example of a SIDS.

Downscaled data on precipitation obtained from RCPs and integrated with agronomy water demand data obtained from the Ministry of Agriculture, Food, Fisheries and Water Resources Management of Barbados. The ET of crops and expected population growth obtained from FAO, Natural Resources Management and Environmental Department. For the base line climate condition, the average monthly data on precipitation aggregated to yearly totals for the period of 1989 to 2012 and current water tariff and charge by different sectors obtained from the Barbados Water Authority (BWA). The aquifer characteristics and demographic information such as household size, tourism arrival, and cruise ship arrival, water consumption by governmental and commercial institutions secured from Barbados's Ministry of Finance and Economic Affairs Annual Reports.

3 Results and discussion

Figure 1 illustrates that the groundwater sustainability will negatively affected by the climate change if there is no intervention imposed on groundwater abstraction. In the absence of groundwater abstraction restrictions, the country's groundwater storage could be depleted by 2100. That is, for a Small Developing State Island such as Barbados, meeting the water demand for food production and urban water uses would be under the threat. With no abstraction intervention, the country would hit its own "Day Zero" - complete groundwater depletion, under all climate scenarios. In contrast, the groundwater sustainability could be maintained in the long run by limiting groundwater abstraction. However, those limitations would results in differential impacts on water demand, food security, and economic livelihoods of water users.

Information plotted in Figure 2 shows that protecting the long run aquifer sustainability would result in sharp decline in available water for abstraction. The severity of the reduction in water availability is linked to the severity of the RCP scenarios. Constraining groundwater abstraction will gradually reduce the amount of water that can be made available for use particularly from the middle of the century onwards, under RCP 8.5. However, even in the absence of any climate change impact, there would be a reduction in water availability after 2080. That is, sustaining the long-term groundwater sustainability requires a decline in the medium run water abstraction, while consumption in the short run could be maintained at present projected levels. However, the mitigation action would be ineffective to secure the long aquifer sustainability and maintaining the historical water use at the same time. Changes in the volume of abstracted groundwater for different sectors and the expected tariff associated with groundwater water are shown in Table 1.

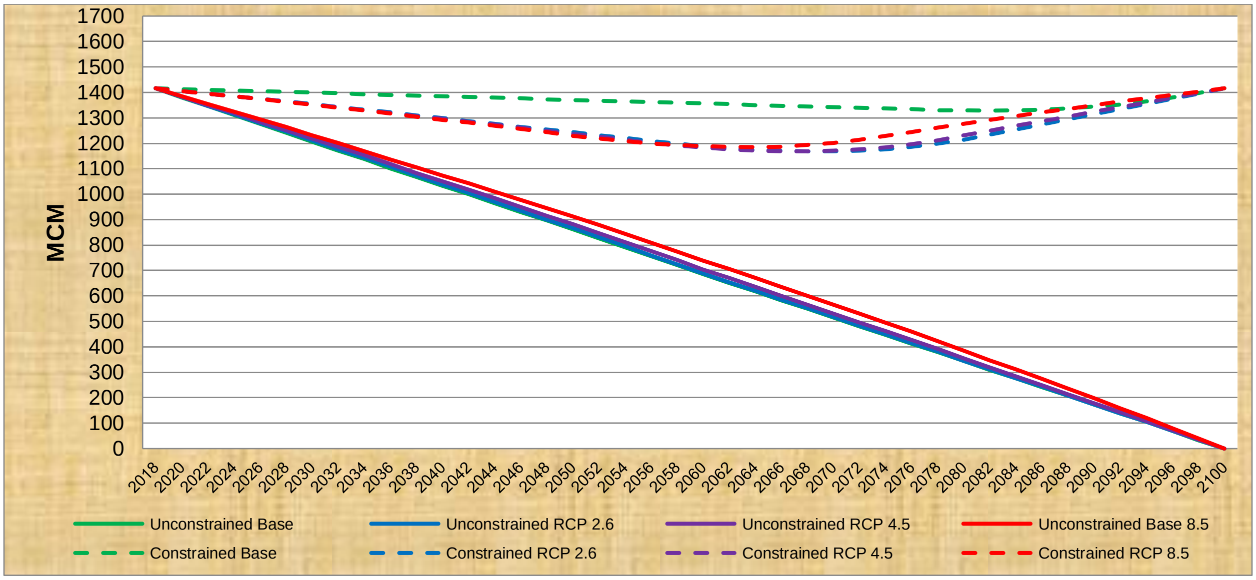

Figure 1. Average annual aquifer storage under different RCP climate scenarios and abstraction policies (Million Cubic Meter)

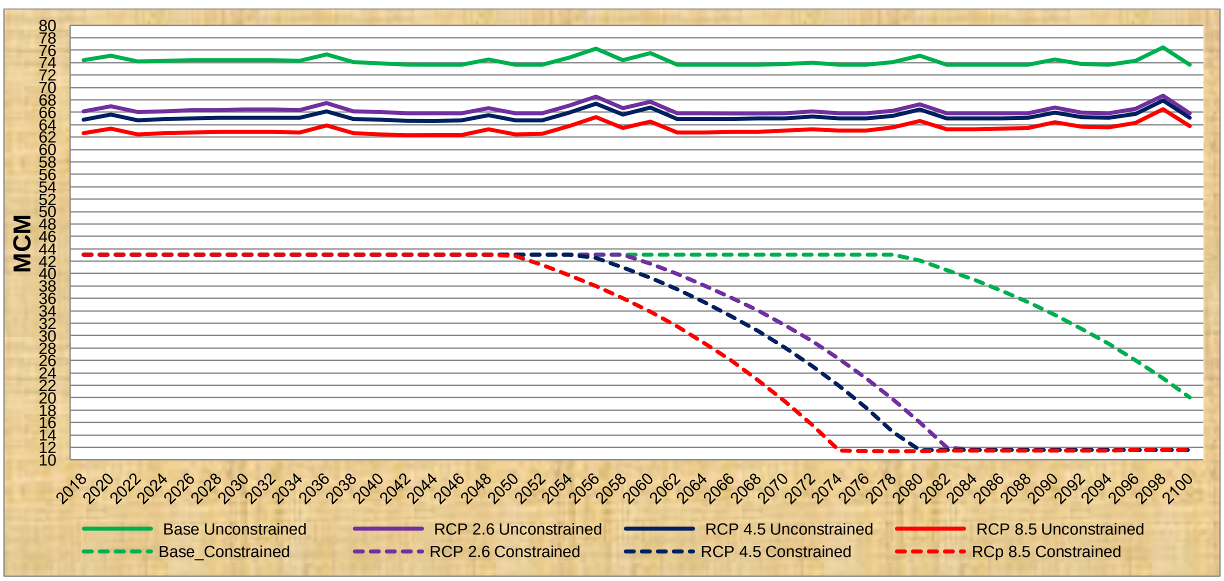

Figure 2. Total groundwater abstraction by RCPs climate scenarios and abstraction policy for the period of 2180- 2100, in MCM.

3.1 Water consumption and economic value

Table 1 shows that in the absence of groundwater abstraction policy, maximizing the consumer and producer welfare can be achieved, assuming there is no change in the per capita water usage across the different climate scenarios. However, satisfying consumers' demand will result in the depletion of the aquifer in the long run. Moving to a policy of constrained abstraction to maintain a given level of aquifer storage implies that urban users and other consumers will compete for the limited available water. The supplier of water for municipal usage would have to bring in higher water tariff, which would result in reduced the water consumption, depending on the demand characteristics of each subsector. The major reduction in water use is expected to be at the household sector, where the consumption would decrease by 35% due to increased tariff by over 70% as compared to unconstrained groundwater abstraction. In contrast, high valued sectors such as the cruise ship and tourism sectors would face smaller reductions in consumption. Given the fact that household use is the major consumer of water with lowest tariff charge, the scarcity induced by climate change would serve to reallocate water to the higher value consumption subsectors.

Table 1 Average water tariff and per capita water consumption by groundwater abstraction policy, climate scenarios, and sector $ US per CM

		Unconstrained Abstraction Policy				Constrained Abstraction Policy			
	Sectors	Base Scenario	RCP 2.6	RCP 4.5	RCP 8.5	Base Scenario	RCP 2.6	RCP 4.5	RCP 8.5
Water Tariff	Households	1.86	1.86	1.86	1.86	3.44	4.06	4.14	4.29
	Tourism	2.57	2.57	2.57	2.57	4.15	4.78	4.86	5.00
	Ship Cruise	4.27	4.27	4.27	4.27	5.85	6.48	6.56	6.70
	Commercial	2.57	2.57	2.57	2.57	4.15	4.78	4.86	5.00
	Government	2.57	2.57	2.57	2.57	4.15	4.78	4.86	5.00
	Others	2.57	2.57	2.57	2.57	4.15	4.78	4.86	5.00
Water Consumption	Households	241	241	241	241	141	100	95	85
	Tourism	15	15	15	15	11.9	10.4	10.2	9.8
	Ship Cruise	0.83	0.83	0.83	0.83	0.7	0.7	0.7	0.6
	Commercial*	2037	2037	2037	2037	1427	1185	1155	1098
	Government*	6222	6222	6222	6222	4730	4135	4062	3922
	Others*	2864	2864	2864	2864	2177	1903	1870	1805

* Water consumption per unit (institution)

3.2 Economic livelihoods

Table 2 summarizes the economic impacts of different climate change scenarios and groundwater abstraction policies on agricultural and urban sectors discounted net revenue and surplus, in addition to the taxpayers payments load for subsidizing the irrigation technology and domestic water uses. Climate change could present challenges for some water users and involve changes for others. While climate change reduces the yield for rainfed crops, agricultural producers could benefit from increased prices for food production. Where farmers apply new irrigation technology, such as drip irrigation, increases in food prices would exceed losses decreased crop yields.

The urban water supplier would only benefit from climate change through constraining the groundwater abstraction. The net annual loss in the water supplier' income under unconstrained groundwater abstraction would range from 1.42 to 1.39 million $ US annually, but under constrained abstraction for base and RCP 8.5 climate scenarios respectively with the increases in prices this could translate to a positive revenue that ranges from 34.40 to 31.34 million $ US. Increasing the water tariffs for all users, as shown in Table 2, could improve the net income for the municipal supplier under the constrained groundwater abstraction policy. These net benefits would decrease slightly with progression to RCP 8.5, because of the increasing pumping depth associated with decreases in storage volume in the aquifer and dropping water levels. Constraining the groundwater abstraction could reduce the urban consumer surplus by 50%., while climate change would reduce the consumer surplus by a maximum of 6%. In other words, the changes in consumer surplus for urban users are more sensitive to the abstraction policy than to climate change. Suggesting that under all scenarios, the water tariff is the major factor that determines the level of water use in the urban sector. Constraining groundwater abstraction should work by increasing the water tariff to signal water scarcity.

Table 2 Average total discounted net benefit, consumer surplus, total welfare, and taxpayers payments by sector, abstraction policy and climate scenarios (Million $ US)

RCPS		Agricultural		Urban		Total	
		Unconstrained	Constrained	Unconstrained	Constrained	Unconstrained	Constrained
Net Benefits	base	25	41	0	8.5	24	50
	RCP2-6	49	61	0	8.5	49	70
	RCP4-5	51	62	0	8.5	51	71
	RCP8-5	57	66	0	8.4	57	74
Consumer Surplus	base	773	762	22	11.6	795	773
	RCP2-6	754	746	22	11.1	776	757
	RCP4-5	752	745	22	11.1	774	756
	RCP8-5	747	742	22	10.9	769	753
Total Welfare	base	798	803	22	20	819	823
	RCP2-6	803	807	22	20	824	827
	RCP4-5	803	807	22	20	825	827
	RCP8-5	804	808	22	19	826	827
Taxpayers Payments	base	-3.96	-0.36	-1.42	34.40	-5.39	34
	RCP2-6	-1.21	-0.22	-1.42	32.31	-2.63	32
	RCP4-5	-0.99	-0.20	-1.41	31.99	-2.40	32
	RCP8-5	-0.60	-0.15	-1.39	31.34	-2.00	31

4 Conclusion

In SIDS, groundwater sustainability is under threat in the long run even without taking into account climate change. Climate change could induce negative socioeconomic consequences such as higher food prices and water tariffs. In the case where no action is taken to sustain the groundwater volumes, food consumers will experience higher food prices, while taxpayers will continue to subsidize groundwater abstraction for food production and household users. The absence of controls to address the negative impacts of climate change on groundwater resources will send the wrong messages to water users and would result in depletion of aquifer storage by 2100. Food consumers will also pay the consequences of inadequate groundwater policies. Limiting groundwater abstraction to current levels, for both food production and urban uses, will require higher water charges for all sectors. Constraining groundwater abstraction will produce relatively more negative impacts on urban welfare as compared to the impacts on food production. The water service provider could minimize its net loss by operating more efficiently under climate change and by constraining the groundwater abstraction. That is, the average deficit in water authority budget could be less with higher climate emission scenarios as less water supplied but at a higher tariff. By constraining groundwater abstraction, the current net financial loss, mainly from supplying the household subsector, could turn to a net gain.

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