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The Critical Importance of Groundwater in Coastal Areas: Impact of Climate Change on Bangladesh Freshwater Resources

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Abstract: Climate change has become an increasing global concern, where more frequent, long lasting and severe weather extremes affect water resources around the world. Freshwater/groundwater resources in Bangladesh are one of the most important aspects of the country, which in future will be significantly affected. Global warming has been affecting the characteristics of drinking water level in many ways. The predicted changing environmental conditions suggest that we should be particularly concerned about the over use of groundwater and its withdrawal. In Bangladesh and nearby countries the effect of climate change has been studied but the nature of relationships between renewable freshwater/groundwater resources, temperature, rainfall and flood affected areas (AA) have not been examined in the manner done in this paper. This article examines the relationships between freshwater/groundwater level in terms of temperature changes, rainfall levels and flood AA during the period of 1962-2015. The quantile regressions show the three variables affect the fresh water levels with varying levels of significance (1, 5, 7 and 10% for example). This study uniquely examines the results from two modelling tools namely, STATA and EVIEWS; and confirms the similarity of the results. Freshwater/groundwater resources are negatively affected by temperature changes, rainfall levels and positively affected by flood affected area coverage –flood allows stagnant water filtration to groundwater over time. Temperature causes evaporation of stored water and rainfall causes runoff in early stages but in flood conditions the effect is positive and this is shown by the quantile regression results.

Keywords: Climate change; Freshwater resources; Temperature; Rainfall, Floods; Modelling; Quantile regression; Bangladesh.

Introduction

Bangladesh is one of the most densely populated countries in the world (Fung et al., 2006). The population of Bangladesh has been increasing day by day. In 1955, there were around 43.10 million people (Worldometers, 2015), but today the population has increased to approx. 160.41 million (Worldometers, 2015; see Figure 1). By 2050, the population of Bangladesh is projected to reach about 202 million (Worldometers, 2015). Also, urbanization has been growing faster in Bangladesh and in keeping with the population growth. Between 1960 and 2010, Bangladesh's urban population grew at an average annual rate of five percent, and the share of the urban population almost doubled, from 15 to 28 percent. Despite strong urban growth, seemingly

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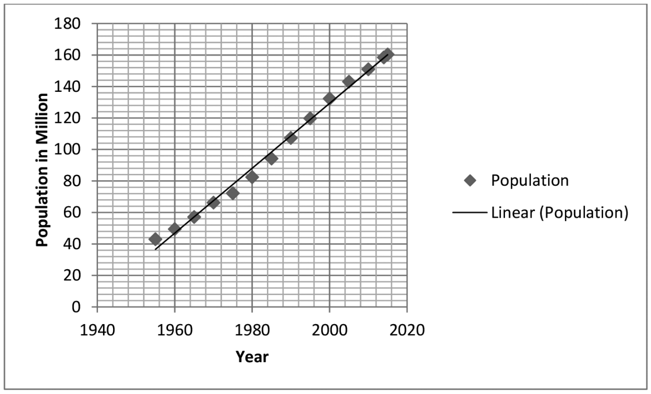

Figure 1: Population of Bangladesh (1955-2015). http://www.worldometers.info/world-population/bangladesh-population/

Bangladesh's urban transition is broadly in line with urbanization of countries at a similar stage of economic development. But Bangladesh still is one of the top 20 urban populations in the world, with an estimated 42 million urban residents (United Nations, 2011). Dhaka city is one of the most densely populated urban areas in the world, with 25,000 people per square kilometre; so the density of the Dhaka metropolitan area is higher than the density of the largest megacities in the world, such as Manila (10,550 people per square kilometer) and Jakarta (10,500 people per square kilometer) (Muzzini and Aparicio, 2013).

The population increase and rapid urbanization has placed much pressure on water security and land use in Bangladesh. It is noted that water resources of Bangladesh are becoming scarce, seemingly not only due to the rate of population growth but also the rate of environmental degradation. Indeed, the effects of climate change are also a factor (Roca and Tularam, 2012; Roca et al., 2015; Tularam and Reza, 2016; Reza et al., 2016). Presently, there is a severe shortage of fresh drinking water/groundwater in Bangladesh; so the northern part of Bangladesh, Coastal Area, and Metropolitan City water supply systems are becoming increasingly valuable to all communities (Tularam and Properjohn, 2011). Human reliance on water has often led to disparity and conflict arising from unequitable resource distribution as well. It is also noted that inadequate access can make water supply systems prime targets for deliberate threats of vandalism and sabotage (Tularam and Properjohn, 2011). Evidently, climate changes will influence rainfall and temperature variability and therefore the changing levels of water availability will affect people's livelihoods and well-being (Tularam and Illahee, 2010, 2007). Besides climatic change, there are other issues such as rapidly changing demographic trends, new economic developments and related land use changes; all of these are placing increasing demands on freshwater/groundwater resources (Tularam and Murali, 2015; Tularam and Properjohn, 2011).

The availability of water in Bangladesh includes rainwater, surface water, and groundwater. In each of these, Bangladesh is facing chronic water shortages and thus the country faces immense challenge to decide how to resolve the water related issues (Roca et al., forthcoming; Tularam and Marchisella, 2014). According to Hossain (2011), the water available on a per capita basis per year is about 9000 cubic metre but this amount has declined from 12,000 m^3 in 1990. It is predicted that the availability will decline to 7500 m^3 in 2025. Bangladesh consists of 230 rivers. Fifty seven are transboundary of which 54 enters from India while three from Myanmar. Ninety per cent of the total water generated in the Ganges-Brahmaputra-Meghna (GBM) is drained from the water basin annually. In the summer, there are floods yearly, while in the winter these rivers are mostly low because of lack of flow upstream. So there is an abundance of water at times (summer) but then there is much too little for use at other times (winter).

The alternating flood and water scarcity during the wet and the dry seasons influence the massive river sedimentation and bank erosion (National Water Policy, 2005). On balance, the groundwater is the most important and reliable source of water supply in Bangladesh (Tularam and Krishna, 2009; Tularam and Properjohn, 2011). Except for few hilly regions, Bangladesh is entirely underlain by water-bearing aquifers at depths varying from zero to 20 m below ground surface. The pumping of groundwater requires much investment by authorities but, more critically, it requires well informed planning such as positioning of the groundwater bores etc. and the nature of their construction (Tularam and Krishna, 2009; Tularam and Singh, 2009; Tularam and Keeler, 2006).

It is noted that the level of groundwater in most countries is often affected by climate change issues relating to temperature, floods and rainfall, for example. In Bangladesh, the water supply in core area of 95 WS towns are primarily based on power operated relatively large diameter shallow and deep tubewells (DTW) usually called production well, whereas in the periphery 23 percent of the urban population is served with manually operated shallow tubewells (STW)[1]. The groundwater is pumped by DTW in urban centres except in areas such as Dhaka and Comilla; in these cases water can be fully replenished in the wet season.

Many of the climate related hazards in Bangladesh can be somehow linked to water (Rabbani et al., 2013). It is possible though that using issues regarding climate change we may be overstating the severity of extreme events such as, droughts, rain falls, floods, sea level rise storms and higher temperatures, but there is evidence of the concern over global warming and its consequences for the effects have indeed intensified and seems to have already changed Bangladeshi climate (Truong and Trück, 2010). In fact it is predicted that by 2050 and 2100, the temperature of Bangladesh will experience an increase of 1.4 °C and 2.4 °C respectively (Agrawala et al., 2003). Either way, Bangladesh has been recognized worldwide as one of the most vulnerable countries to bear the impacts of global warming and climate change by a number of authors (Agrawala et al., 2003; Tularam and Marchisella, 2014).

Summary

The unique geographic location, dominance of floodplains, low elevation from the sea, high population density, high levels of poverty, and overwhelming dependence on nature, its resources and services are related to the risks to climate change effects. Water related impacts of climate change will likely be the critical issue for Bangladesh—largely concerning coastal and riverine flooding, but also enhancing the possibility of winter (dry season) drought in certain areas (Agrawala et al., 2003; Annual Flood Report, 2014). The global warming has been already affecting the characteristics of water level in many ways (Mirza, 2002) and the effects of increased flooding will be the problems facing Bangladesh as the frequency of floods have increased over time. Thus both coastal flooding (from seawater intrusion and river water), and inland flooding (river/rainwater) are expected to increase in future as well (Agrawala et al., 2003; Annual Flood Report, 2014).

The changing environmental conditions predicted suggest that we should be particularly concerned about the "over use and pumping" of groundwater and particularly its withdrawal in the developing coastal areas more generally. While in Bangladesh and its nearby countries the nature of the effect of climate change has been studied well, what is lacking are the results concerning the nature of relationships between renewable internal freshwater/groundwater resources (labelled freshwater in this study) and the nature of relations with varying temperature and rainfall over time, for example. This paper therefore undertakes the challenge to examine the changing level of freshwater/groundwater in Bangladesh using data gathered for a number of years. Further investigation is needed as the historical trends suggest increased temperatures, thus evapotranspiration in all types of storage areas. Exactly how temperature, rainfall and other factors influence groundwater levels is also not so clear given time scales of infiltration processes, so this also needs investigation particularly during and after the wet and dry periods. Clearly, irrigation is going to be crucial for future survival in the water scarce areas in Bangladesh; so in the end groundwater levels may determine the survival of smaller communities, animals, and even humans in many areas.

The main aim of this paper is to examine the impact of climate related factors to the country's freshwater/groundwater resources. Essentially, we examine the effect of temperature, rainfall and the amount of area affected by flood (AA) on freshwater/groundwater resources. This is conducted using quantile regression. In particular, the paper examines correlation in the data and then analyses linearly the relationships to groundwater levels at various levels of response variable. The paper is organized as follows. This section has discussed why water arability is issue in Bangladesh. In the following section, we present a further background of Bangladesh. The next one outlines the data and methodology employed in the study while the penultimate section discusses the analysis and empirical results, and conclusions are presented in the last one.

Background

The greenhouse effect is a change in the conditions of the world that is related to the global climate and is now known to be mostly due to human activities. The IPCC "Business-as-Usual emissions scenario" has predicted the sea water level rise forced by greenhouse effects to be around 20 cm (in terms of the global mean sea level) by 2030, and also about 65 cm by the end of next century (Warrick et al., 1996). The main threats are increased flooding, drainage congestion, decrease of fresh water availability, disturbance of morphological

[1] http://users.physics.harvard.edu/~wilson/arsenic/conferences/Feroze_Ahmed/Sec_2.htm

processes, salinity intrusion, frequent cyclone and storm surge flooding apart from others. According to IPCC (2007), Bangladesh may suffer from more extreme weather events such as heat waves, floods, cyclones, landslides, tornados, and possibly earthquakes as well. It seems then that the climate change risks in the water sector would possibly bring great challenges to water resource management groups. Also, under new climate change conditions, the monsoon rainfall level is predicted to increase by about 10-15% by the year 2030, particularly during the summer monsoon, and this could impact on the flood-prone areas in Bangladesh.

Bangladesh is between 20°30′ and 26°40′ north latitude and 88°03′ and 92°40′ east longitude on the world map; being of an area of about 147,570 sq.km. The weather is sub-tropical monsoon climate with an annual average precipitation of 2300 mm, with some variation from 1200 mm in the north-west to over 5000 mm in the north-east. The Bay of Bengal is in the south, with Indian borders in the west and east; while Myanmar borders in the south-east. The major Monsoon flooding in 25% of the country is assumed to be beneficial to crops, ecology and environment; sometimes the inundation is greater—thus causing both direct and indirect damages and this in turn leads to a

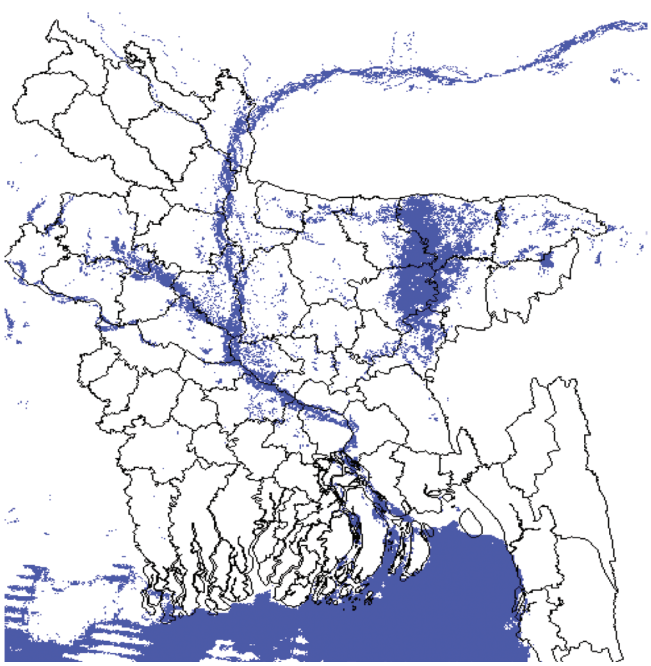

Figure 2: Map of Bangladesh with water, 2014. https://www.google.com.au/search?q=Bangladeshi+MAP+with+water&biw=1920&bih=979&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwjat_PB7ffPAhVDOJQKHYckCvsQsAQIGg&dpr=1#imgrc=uJ-Oq2b66Bi51M%3A

number of inconveniences to the general population (Annual Flood Report, 2014). The Ganges-Brahmaputra-Meghna basin is predicted to benefit from increased rainfall in the monsoon in future; predictions are to be about 4-8% by the 2020s and 9-10% by the 2050s (Tanner et al., 2007).

Clearly, the nature of the changing climate will influence Bangladesh as it will become rather vulnerable to large volumes of water flowing down these rivers leading to riverine and other types of flooding. It is also clear that Bangladesh will suffer from more extreme weather events such as heat waves, cyclones, landslides, tornados and earthquakes. Such changes will have a direct impact on the country's freshwater resources and in particular impact on their groundwater levels, both of which are critical to their survival (IPCC, 2007).

Data and Methodology

Data

The water data was obtained from the renewable internal freshwater resources. The data included time series data on temperature, rainfall and flood data (affected area) for the period of 1962-2015 (Figure 3). These yearly time series data were collected from the website of World Bank [http://data.worldbank.org/country/bangladesh], Bangladesh Bureau of statistics [http://www.bbs.gov.bd/], Dhaka Weather [http://climatevo.com/2014,dhaka,bd], and from the Annual Flood Report 2014.These yearly data utilized is in standardized form. The log form to reduce magnitude and variability.

Methodology

As noted, this study used the Quantile regression model method, which examines the relation between a set of predictor variables and specific percentiles (or quantiles) of the response variable. The quantile analysis can specify changes in the quantiles of the response. For example, a median regression (median is the 50th percentile) of freshwater resource on climate change characteristics specifies the changes in the median freshwater level as a function of the predictors. While linear regression models can address the question "is predictor variable important?", it cannot answer an important question such as: "does predictor variable influence the response differently for low response values than for those with average or high response variable values", for example. A more comprehensive picture of the effect of the predictors on the response variable can be obtained using Quantile regression. The effect of predictor variable on median freshwater

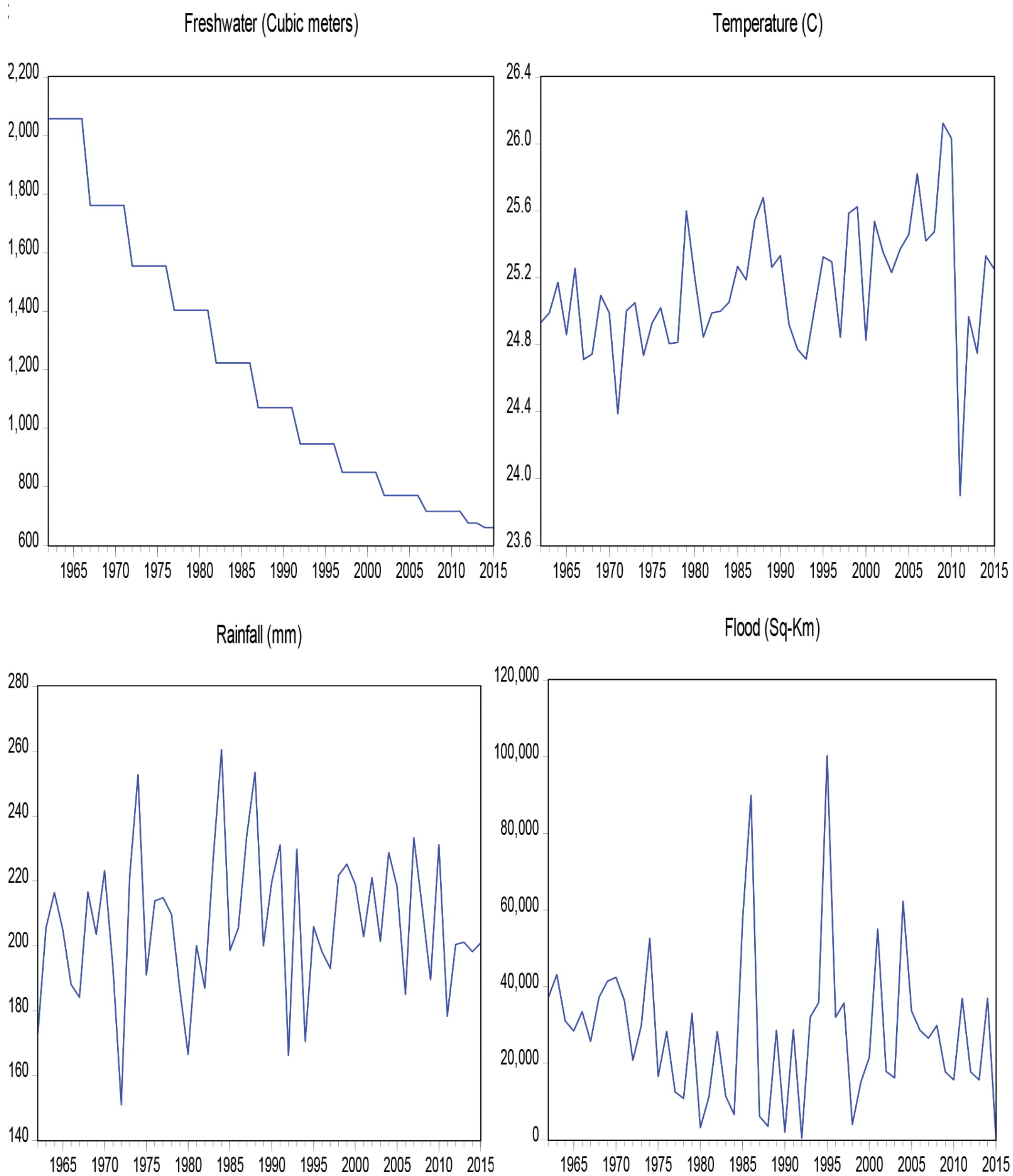

Figure 3: Freshwater, temperature, rainfall and flood movement, 1962-2015.

resource can be compared to its effect on other quantiles of the resource. In linear regression, the regression coefficient represents the increase in the response variable produced by a one-unit increase in the predictor variable associated with that coefficient. The quantile regression parameter estimates the change in a specified quantile of the response variable produced by a one-unit change in the predictor variable. This process can help us compare how some percentiles of the response variable may be more affected by certain climate change characteristics than other percentiles. This is shown, for example, by changes noted in the size of the regression coefficients.

In this study we examine the relationships between freshwater/groundwater (response) and temperature, rainfall and flood AA using the method of quantile regression developed by Koenker and Bassett (1978) – which is a well established method often used in the statistical analysis of time series data. The quantile regression models concern relationships between a set of control variables and specific percentiles (or quantiles) of the outcome variable. Let (y_i, x_i) $i = 1,\dots, n$, be a sample from these climate change variables, where x_i is a $k \times l$ vector of regressors. Using work done by Koenker and Bassett (1978) and Buchinsky (1998) we can write the quantile regression model (Equation 1) as follows.

$$y_i = x'_i \beta_\theta + \varepsilon_{\theta i} \quad (1)$$

$$\text{Quant}_\theta (y_i |x_i) \inf\{y{:}F\ y|x)\ \theta\} = x'_i \beta_\theta \quad (2)$$

$$\text{Quant}_\theta (\varepsilon_{\theta i}|x_i) = 0 \quad (3)$$

where $\text{Quant}_\theta (y_i |x_i)$ denotes the θ^{th} conditional quantile of y_i on the regressor vector x_i and β_θ is estimated for different coefficient values of F, while ε_θ is the distribution of the error term.

Empirical Results

Descriptive Statistics

Table 1 shows the mean of freshwater/groundwater as 7.018, the maximum is 7.629 and the minimum is 6.492. The mean of temperature is 3.224, the maximum is 3.262 and the minimum is 3.173. The mean of rainfall is 5.325, the maximum is 5.562 and the minimum is 5.016. The mean flood AA is 9.781, the maximum is 11.407 and the minimum is 0.000. It is noted that the largest positive mean (9.781%) is for flood AA whereas the temperature has the lowest positive mean (3.224). As the skewness values of temperature, rainfall and flood are in general negative – asymmetric tail, whereas the skewness values of freshwater is positive i.e. the symmetric tail. The kurtosis values of temperature, rainfall and flood are higher than three; thus the distribution could be fat-tailed. Subsequently the Jarque-Bera results are statistically significant. Thus, the assumption of normal distribution is not fulfilled and quantile regression method is appropriate even when usual linear regression is applied; so quantile is appropriate, even when the linear regression is appropriate for first or initial analyses because linear regression is usually rather robust in many cases (Tularam and Amri, 2012).

Table 1: Descriptive statistics

	Freshwater	*Temperature*	*Rainfall*	*Flood AA*
Mean	7.02	3.22	5.33	9.78
Median	6.98	3.22	5.32	10.26
Maximum	7.63	3.26	5.56	11.41
Minimum	6.49	3.17	5.02	0.00
Std. Dev.	0.36	0.02	0.11	1.63
Skewness	0.19	-0.13	-0.34	-4.22
Kurtosis	1.75	4.29	3.29	24.71
Jarque-Bera	3.87	3.89	1.24	1265.95
Probability	0.14	0.14	0.54	0.00
Sum	379.02	174.11	287.58	547.76
Sum Sq. Dev.	7.00	0.01	0.64	146.08

Correlation Matrix

Table 2 presents the correlation matrix between fresh water and climate variables. The matrix shows a positive and negative correlation between freshwater/groundwater, temperature, rainfall and flood. Temperature and rainfall are negatively correlated with freshwater/groundwater, whereas flood AA is found positively correlated with freshwater/groundwater. Rainfall and flood are positively correlated with temperature. Similarly, the positive correlation is found between rainfall and flood AA.

Table 2: Correlation matrix

	Freshwater	*Temperature*	*Rainfall*	*Flood AA*
Freshwater	1			
Temperature	-0.353	1		
Rainfall	-0.112	0.2043	1	
Flood	0.256	0.09265	0.0629	1

Regression (τ = 0.9) Results—Individual

In the following, the 90% quantile results are presented as an example; and all other results are summarized and presented in either tables or graphs. We estimate equation (1) using the Quantile Regression method. We choose 90 per cent quantiles and using it we examine the nature of relationships between temperature, rainfall and flood. Tables 3-5 show that the estimated coefficients are positive and the temperature, rainfall and flood are significant at the 1% level of significance. Thus, it is noted that these three climate variables individually influence the freshwater/groundwater values.

Regression (τ = 0.9) Results—Combined

We also examine the relationships between freshwater/groundwater and temperatures, rainfall and flood altogether. In Table 6, the results show that the estimated coefficients of temperature and flood are positive while the estimated coefficient of rainfall is negative. However, these three climate variables are statistically significant at the level of 5% significance. The quantile graph shows how the effects of temperature, rainfall and flood vary over different quantiles (Figures 4-6).

We note that for the low values of freshwater (FW) (or groundwater (GW)), the temperature has a low to positive effect but then lowers to a negative effect when FW/GW are at medium values (50%); and then increases but remains negative for high water reserves due to the evaporative or heating effect on groundwater as well as storage of water resources. So, the effect on resources is different at different levels of water

Table 3a: Quantile regression (τ = 0.9)—Freshwater vs temperature

Variable	*Coefficient*	*Std. Error*	*t-Statistic*	*Prob.*
Temperature	2.339	0.025	90.494	0.000
Pseudo R-squared	-0.022	Mean dependent var		7.018
Adjusted R-squared	-0.022	S.D. dependent var		0.363
S.E. of regression	0.651	Objective		3.305
Quantile dependent var	7.473	Restr. objective		3.233
Sparsity	2.033			

EVIEWS: Temperature is significant

Table 3b: Quantile regression (τ = 0.9)—Freshwater vs temperature

Raw sum of deviations 6.467885 (about 7.4736357) Number of obs = 54
Min sum of deviations 5.996984 Pseudo R^2 = 0.0728

Freshwater	*Coef.*	*Std. Err.*	*t*	*P>|t|*	*[95% Conf. Interval]*	
Temperature	-13.05271	4.99767	-2.61	0.012	-23.08127	-3.024154
_cons	49.57082	16.11377	3.08	0.003	17.23618	81.90547

Temperature is significant

Table 4a: Quantile regression (τ = 0.9)—Freshwater vs rainfall

Variable	*Coefficient*	*Std. Error*	*t-Statistic*	*Prob.*
Rainfall	1.432	0.019	75.197	0.000
Pseudo R-squared	-0.187	Mean dependent var		7.018
Adjusted R-squared	-0.187	S.D. dependent var		0.363
S.E. of regression	0.740	Objective		3.839
Quantile dependent var	7.473	Restr. objective		3.233
Sparsity	2.434			

EVIEWS: Rainfall is significant

Table 4b: Quantile regression (τ = 0.9)—Freshwater vs rainfall

Raw sum of deviations 6.467885 (about 7.4736357) Number of obs = 54
Min sum of deviations 6.243755 Pseudo R^2 = 0.0347

Freshwater	*Coef.*	*Std. Err.*	*t*	*P>|t|*	*[95% Conf. Interval]*	
Rainfall	-.6877768	.4086615	-1.68	0.098	-1.507816	.1322625
_cons	11.17242	2.176816	5.13	0.000	6.804315	15.54052

Rainfall not significant at 5% but is at 10%

Table 5a: Quantile regression (τ = 0.9)—Freshwater and flood affected area

Variable	*Coefficient*	*Std. Error*	*t-Statistic*	*Prob.*
Flood	0.786	0.020269	38.786	0.000
Pseudo R-squared	-1.662	Mean dependent var		7.018
Adjusted R-squared	-1.662	S.D. dependent var		0.363
S.E. of regression	1.100	Objective		8.609
Quantile dependent var	7.473	Restr. objective		3.233
Sparsity	4.464			

Flood significant

Table 5b: Quantile Regression (τ = 0.9)—Freshwater and flood affected area

Raw sum of deviations 6.467885 (about 7.4736357) Number of obs = 54
Min sum of deviations 5.50389 Pseudo R^2 = 0.1490

Freshwater	*Coef.*	*Std. Err.*	*t*	*P>|t|*	*[95% Conf. Interval]*	
Flood	.1846574	.0436168	4.23	0.000	.0971338	.272181
_cons	5.629497	.4359	12.91	0.000	4.754799	6.504194

Flood AA is significant.

Table 6: Quantile Regression (τ = 0.9) results—Freshwater vs all main effects

Raw sum of deviations 6.467885 (about 7.4736357) Number of obs = 54
Min sum of deviations 5.142526 Pseudo R^2 = 0.2049

Freshwater	*Coef.*	*Std. Err.*	*t*	*P>|t|*	*[95% Conf. Interval]*	
Temperature	-9.327498	4.217903	-2.21 0.032	-17.79941	-.8555898	
Rainfall	-.7731334	.5953511	-1.30 0.200	-1.968931	.4226645	
Flood	.1598868	.0672012	2.38	0.021	.0249092	.2948643
_cons	40.03532	13.28516	3.01	0.004	13.35128	66.71936

Temperature and flood significant at 5%

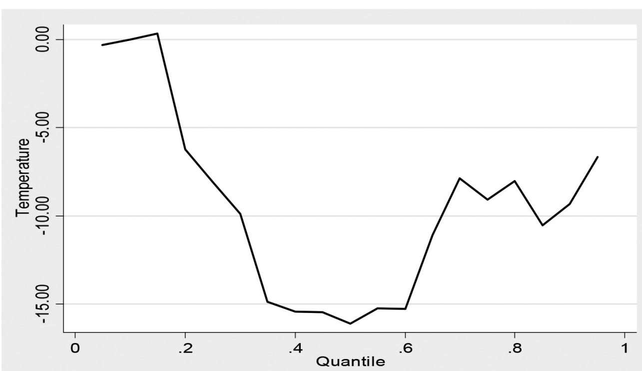

Figure 4: Quantile graph for temperature.

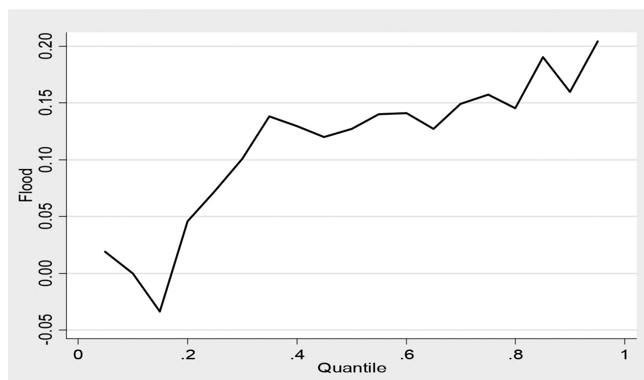

Figure 6: Quantile graph for flood affected area.

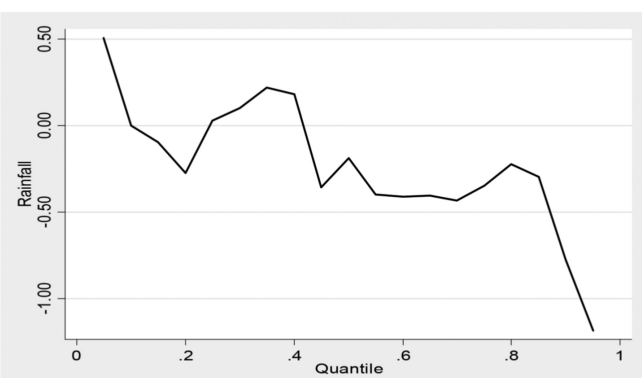

Figure 5: Quantile graph for rainfall.

resources held. The effect of heat on low storage levels (10%) is close to zero; this is probably because the groundwater levels are too low to be influenced directly; but clearly pumped or dam levels will be affected even when the resources held are low; that is, they will be negatively affected. If the water level held is high, then as expected via evaporation and expiration via trees etc. will be a cause of any change in water levels particularly due to extra heating periods; but the effect will be less noted overall, if the high levels of water are already available. We note that there is a quadratic effect of quantiles on temperature showing a point of minimum effect of high temperatures on FW/GW held.

Initially for low values of the response variable the effect of rainfall is positive but around when considering the 50% held water resource, the effect of rainfall is negative; and for higher values (90%) it has a greater negative effect. This can be explained by the fact that when water resources are low then rainfall has a positive effect on water resources that are in dams, groundwater etc. but when water resources held are around the middle (50%) levels then the effect of rainfall is negative in that much of rainfall will be runoff and little can be infiltrated to groundwater stored, except there will be some increase noted in dams (if there are any). Bangladesh is not known for its dams but rather depend largely on groundwater for human use. It is to be noted that the time for infiltration of surface water to groundwater is high. So for the rainfall water to be effective it needs to be stagnant or still for a period of time over the areas affected for successful infiltration to occur; also if capacity is reached in groundwater level runoff will occur; also, if very dry conditions exist, much of the rainfall will runoff to sea instead of infiltrating to groundwater. Dams may become full but loss will also occur if they are full already.

In case the flood AA is large the effect on held water resource/groundwater is mostly positive even when the water resources held is low, middling, or high. Although in the initial stages when the water resource is low, then the effect is zero or slightly negative due to time lag. The effect of flood AA on middle waterlevels is positive and for high water resources held, the effect is higher and also positive. This can be explained by the fact that when water resources/groundwater levels are low then the effect of greater flood AA is not as significant as the flood water takes a while to infiltrate to groundwater and into other storage facilities perhaps. Nonetheless, the effect of the areas of floods AA in square km to general storage of freshwater/groundwater is positive as expected since the longer length of stay in affected areas do affect the groundwater storage levels.

General Analysis

To investigate the nature of the relationships more generally, the STATA linear regressions were investigated and are presented in Tables 8 to 10; the results further confirm the significance and directions of the coefficients noted in quantile regression. In each case the individual variables of temperature and flood influence the groundwater and thus freshwater resource availability at 1 and 7% respectively. Although not significant in the linear regression case in STATA, the rainfall was noted to be significant when EVIEWS analysis was used, but importantly, the direction of coefficient was the same in all cases except as shown in quantile regression (Table 7).

Table 7: Coefficients results with freshwater – see quantile graphs

	OLS	*10th Quant*	*20th Quant*	*30th Quant*	*40th Quant*	*50th Quant*	*60th Quant*	*70th Quant*	*80th Quant*	*90th Quant*
Temp	-8.649	4.441	-6.214	-9.897	-15.45	-16.127	-15.30	-7.871	-8.038	-9.327
Rainfall	-0.183	-1.294	-0.273	0.102	0.180	-0.188	-0.411	-0.433	-0.221	-0.773
Flood AA*	0.111	-1.251	0.045	0.100	0.129	0.127	0.140	0.149	0.145	0.159

*Affected area in sq. km

Table 8: Simple linear regression of the freshwater vs temperature (significant)

Source	*SS*	*df*	*MS*		
				Number of obs	= 54
				F(1, 52)	= 7.42
Model	.874614132	1	.874614132	Prob > F	= 0.0087
Residual	6.12649699	52	.11781725	R-squared	= 0.1249
				Adj R-squared	= 0.1081
Total	7.00111112	53	.132096436	Root MSE	= .34325

Freshwater	*Coef.*	*Std. Err.*	*t*	*P>|t|*	*[95% Conf. Interval]*	
Temperature	-8.27917	3.038666	-2.72	0.009	-14.3767	-2.18164
_cons	33.71275	9.797441	3.44	0.001	14.05275	53.37275

Table 9: Simple linear regression of the freshwater vs rainfall (not significant)

Source	*SS*	*df*	*MS*		
				Number of obs	= 54
				F(1, 52)	= 0.67
Model	.088972802	1	.088972802	Prob > F	= 0.4170
Residual	6.91213832	52	.132925737	R-squared	= 0.0127
				Adj R-squared	= -0.0063
Total	7.00111112	53	.132096436	Root MSE	= .36459

Freshwater	*Coef.*	*Std. Err.*	*t*	*P>|t|*	*[95% Conf. Interval]*	
Rainfall	-.3735941	.4566421	-0.82	0.417	-1.289914	.5427253
_cons	9.008491	2.432394	3.70	0.001	4.127535	13.88945

Table 10: Simple linear regression of the freshwater vs flood affected area

Source	*SS*	*df*	*MS*		
				Number of obs	= 54
				F(1, 52)	= 3.66
Model	.460129112	1	.460129112	Prob > F	= 0.0613
Residual	6.91213832	52	.127588116	R-squared	= 0.0657
				Adj R-squared	= -0.0478
Total	7.00111112	53	.132096436	Root MSE	= 35467

Freshwater	*Coef.*	*Std. Err.*	*t*	*P>|t|*	*[95% Conf. Interval]*	
Flood	.0975592	.0510092	1.91	0.061	-.0047982	.1999166
_cons	6.04827	.5097778	11.86	0.000	5.025326	7.071214

Significant at 7%

Conclusion

The objective of this study was to critically review the impact of climate change on freshwater/groundwater resource of Bangladesh region and also conduct various quantile regression analyses to answer questions such as how levels of water resources are affected by climate change variables – in particular, variables such as temperature and rainfall in Bangladesh. This article examined the relationships between freshwater/groundwater availability and temperature, rainfall and flood AA of Bangladesh for the period of 1962-2015; thus the data gathered was extensive. The results show that these three variables affect the freshwater/groundwater at 90% quantile level with a high level of significance (0.01). The results of this study makes the link between climate change variables and Bangladesh water resources clearer. The significant positive and negative nature of the temperature and rainfall effects can be explained for example by temperature creating much evaporation and thus condensation, with high flood affected areas pertaining to large coverage of stagnant water for some periods of time that ultimately—while causing pollution of surface and groundwaters, nevertheless—allows the groundwater levels to increase, thus freshwater or potable groundwater availability to districts to increase. Although good for tank and dam storage, the combined effect appears to be both positive and negative depending on the nature of the quantile examined. The negative effect of rainfall may be due to the quick runoff early in time of raining process, and thus lower infiltration levels to groundwater levels earlier on in time; but when a large amount of rainfall periods exist causing flooding of large areas, then it may be favourable to the freshwater/groundwater availability; and this may be represented by the positive effect. While the relationships between the variables have been made clearer by this study than that which existed in earlier works, there are still many areas related to the analysis that need further research.

It is important to note that groundwater is the most important source of drinking and thus considered as a large percentage of the freshwater resource in Bangladesh. While the possible impacts of some climate change variable effects on availability of water and water quality has been more accurately explained here, the overall influence is still unclear and need further work as one of the areas noted; but also an increasing focus on rainfall fluctuations, sea level intrusion and the level of flood affected area variability needs further study. It is clear that the changes in predictor variables used in this study do directly impact groundwater resources, and this in turn will tend to influence the livelihoods of the populations who rely on agriculture, in relation to the amount of food produced etc. The almost exponential decrease in availability of freshwater over time in Bangladesh is rather alarming, and this decreasing availability per person shows that there are a number of challenges related to groundwater and its security, as well as its management in Bangladesh. The groundwater/freshwater, temperature, rainfall and flood affected areas scenarios analysed in this study show that there are significant effects of temperature and flood covered areas on 90% quantile response values. The analysis shows that different tools such as EVIEWS and STATA as well as other analytical methods may not have indicated significance at times—as shown here in some cases—but the trend has similarity and this aspect therefore needs to be considered as important for longer term planning of the supply of potable/ groundwater. In this regard, Bangladesh government and water managers need to pay keen attention to the issue of climate change adaptation early on rather than after the event. Appropriate freshwater/groundwater policies and regulations should be developed together with a long-term framework and strategies to help develop water security for future generations.

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