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Water and Growth Report 2

Exploring the effect of hydroclimate variability on economic growth in Sub-Saharan Africa:

a water security index

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ABSTRACT

Recent econometric studies provide evidence that climate variability in general, and rainfall variability in particular, has a negative effect on economic growth in the countries of Sub-Saharan Africa. In this study, we explore the factors that may explain why some countries are more resilient to climate variability than others. We use a range of data that is representative of the possible sources of resilience that are commonly hypothesized in the literature, including the state of water resources and water use, the inventory of infrastructure and the quality of institutions. Two analyses are undertaken. In the first, cross country regressions are used to explore aggregate associations of climate and resilience variables with economic growth. In the second, panel regressions for individual countries are performed with drought and flood indices. The results of these regressions are used to specify a water security index. The water security index is then analyzed through the prism of the resilience variables to draw inferences in regard to the sources of resilience that contribute to more water security. The results of these analyses are informative. Cross country regressions confirm the negative association between rainfall variability and economic growth within Sub-Saharan Africa. They also revealed strong associations between Foreign Direct Investment (FDI) and infrastructure inventory and economic growth. An index that accounts for climate variability and water storage (Seasonal Storage Index) is also strongly associated with both FDI and economic growth. The analysis of the Water Security Index revealed that more internal renewable water resources and irrigated agriculture as a percent of agricultural area were associated with more resilience to hydroclimate variability. Water storage was not a strong indicator of resilience, although when controlling for hydrologic variability with the SSI, it does become more important. There were no strong associations with institutions and weak positive associations with road density and phones.

1. Introduction

Recent studies by the World Bank and the International Research Institute for Climate and Society have provided striking evidence of the link between the economic development of nations and the variability of their climate. These results imply that economic development can be hampered by what Grey and Sadoff (2006) term difficult hydrology - characterized by high levels of hydro-climatic variability (e.g. high frequency of floods and droughts, dramatic seasonal variations). Such variability marks the African continent more than any other region in the world, yet is often an overlooked impediment to economic growth and seldom discussed in country assistance strategies. In general, investments in the water sector (both hardware and software) may help better achieve reliable water supply (for productive uses - agriculture, industry, urban) and protection from these extreme and uncertain events. That is, such investments can help countries achieve 'water security'.

The magnitude and types of investment needed to achieve this water security are dependent on the vulnerability of the economy and populace to climate variability. In theory, without a minimum level of water security, a country may not be able to produce significant sustainable returns from investment nor break the inertia of stagnant economic growth. While the concept of water security may be clear, the practical application of the concept is hindered by a lack of understanding as to what the attributes of water security are. Understanding the linkages between water security and broad-based macroeconomic improvements is critical to country assistance strategies and sector strategies. The aim is to develop these concepts to help guide the prioritization and selection of Bank investments in the water sector.

In this study, we explore the effects of climate variability on economic growth in SSA to identify the attributes that contribute to water security. The first analysis uses cross-country regressions to identify general associations among climate variables and economic variables. The second analysis uses panel regressions for individual countries on economic growth and climate indices that represent flood and drought effects. The results are used to define a water security index. The attributes of countries with low and high values of water security are then analyzed in terms of variables that are hypothesized to provide resilience to climate variability. We term these factors resilience variables. Finally, conclusions are drawn from the results of the two analyses.

2. Explaining Climate and Growth: Cross Country Regression Analysis

This section describes the correlation analysis conducted between summary statistics of climate and variability, economic indicators and infrastructure variables. Several studies have documented a negative relationship between rainfall variability and economic growth (Brown and Lall, 2006; Brown et al., 2008; Barrios et al., 2008). However, the causes that underlay this effect have not been identified. Grey and Sadoff (2006) provide a conceptual explanation that relates stalled economic growth in many poor countries to the insufficient means that these countries have to manage their hydrologic challenges, such as drought and flood. This results from insufficient infrastructure and water management institutions. Other authors do not address the issue directly, but assert generally that the quality of institutions is the primary factor that influences economic growth (Rodrik et al., 2001). In this section, we explore possible causes of the climate effect by exploring secondary associations between factors that are commonly invoked as contributing to or mitigating the climate effect.

Cross country regressions were performed with a very wide variety of variables for forty-two countries of Sub-Saharan Africa. The variables included measures of infrastructure, institutions, geography, trade, aid and investment, and communications. In general the regressions were complicated by the homogeneity of the countries in many of the variables. That is, there are only minor differences between many countries in many of the variables. However, some robust patterns did emerge that appear informative. Here only those informative results are reported. In all cases, correlations are indicated on the figure and a correlation of magnitude 0.26 or higher is statistically significant at the 90% confidence level.

In a previous study, a global relationship between rainfall variability and per capita GDP was presented (Brown and Lall, 2006). Here, we investigated the same relationship within the countries of Sub-Saharan Africa. The coefficient of variability of intra-annual rainfall (CVM – month to month changes in rainfall) and the coefficient of variability of interannual rainfall (CVI – year to year changes in rainfall) were regressed with per capita GDP and GDP growth. Somewhat surprisingly, given the homogeneity of economic growth and climate in SSA, the negative associations were strongly significant for the case of the CVM. As shown in figure 1, countries with higher within year, month to month rainfall variability (CVM) tend to have lower per capita GDP and lower rates of economic growth. This is consistent with the result at the global level, indicating that the variability of rainfall and thus water resources, present challenges to economic growth. Consequently, the ability to manage variability in water resources may be a probable source of resilience.

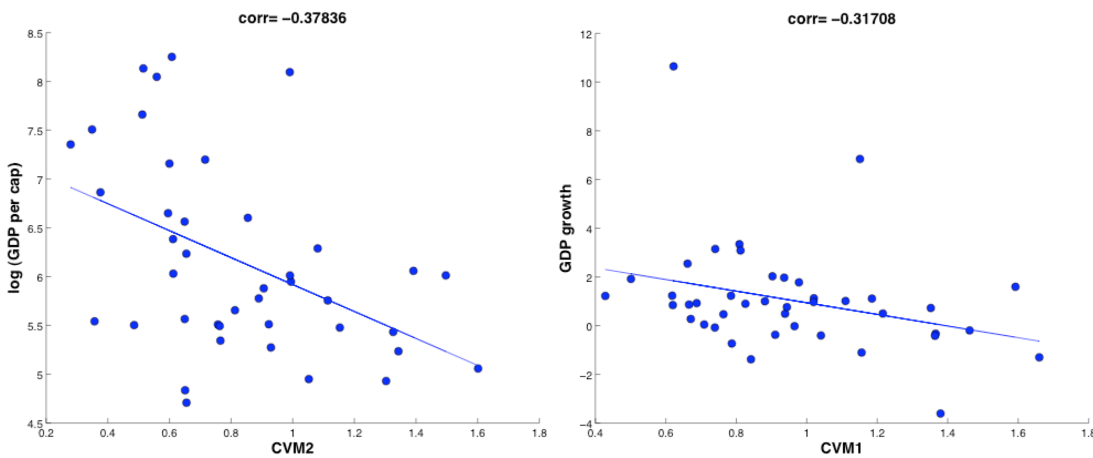

Figure 1. Scatter plots of log per capita GDP (left) and GDP growth (right) versus CVM, the coefficient of intra-annual rainfall variability.

Traditionally, the primary means of managing hydrologic variability is through investments in water storage. Here we investigated the association between water storage, in terms of per capita dam volume, and economic growth rates within SSA. The result indicated no association between these two variables. Initially surprising, upon closer inspection the lack of association may be fairly plausible. The volume of water storage that a country requires is a function of water demand, which is closely related to population in the largely agricultural countries of SSA, and also of hydrologic variability. For this reason, water storage volume data that controls only for population (per capita values) may not be informative since hydrologic variability has not been considered. The seasonal storage index (SSI) was created to incorporate both hydrologic variability and water demand into a single variable (Brown and Lall, 2006). The value of the SSI is then calculated as the volume of water storage a country has relative to a design value of storage a country should have calculated according to its water demand and hydrologic variability. A drawback of the SSI is that it spatially aggregates water and demand data at the national level and so does not account for spatial variability. As a result, countries that have adequate rainfall as indicated by the spatial average for the entire country will have a design storage value of zero. Therefore, the SSI is only calculated for countries with positive design storage values.

The regression of SSI on economic growth in the countries of SSA is consistent with the expected effect of water storage in countries where hydrologic variability appears to have negative impacts. Figure 2 shows the results of the regression. There is a positive association between GDP growth and water storage as indicated by the SSI. Note that the sample is limited to countries with positive SSI values for the reasons stipulated above. Still, visual inspection of the figure confirms a relationship between economic growth and water storage that is not exhibited when only dam volume data is used.

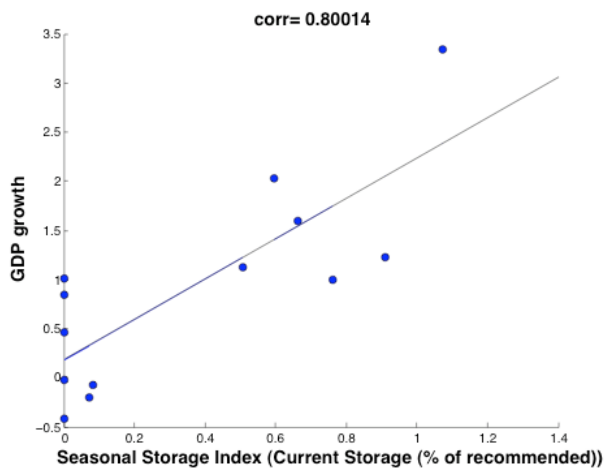

Figure 2. Scatter plot of GDP growth versus Seasonal Storage Index. The figure shows a positive association between economic growth and water storage relative to a design value based on hydrologic variability and water demand.

The possible effect of infrastructure in general, and water storage in particular, was also revealed through an interesting secondary association with foreign direct investment (FDI). FDI and official development assistance (ODA) were evaluated for their association with economic growth in SSA. The results, shown in figure 3, indicate a slight positive association between FDI and growth (despite a very high correlation coefficient that is influenced unduly by a single point), while ODA is slightly negatively associated. Here the question of causation is relevant. It is probable that ODA is preferentially delivered to the places that are in need, and these would often be those places with low rates of growth. In contrast, FDI may be attracted to places where the conditions for growth are in place; thus the growth rate may be the cause of more FDI.

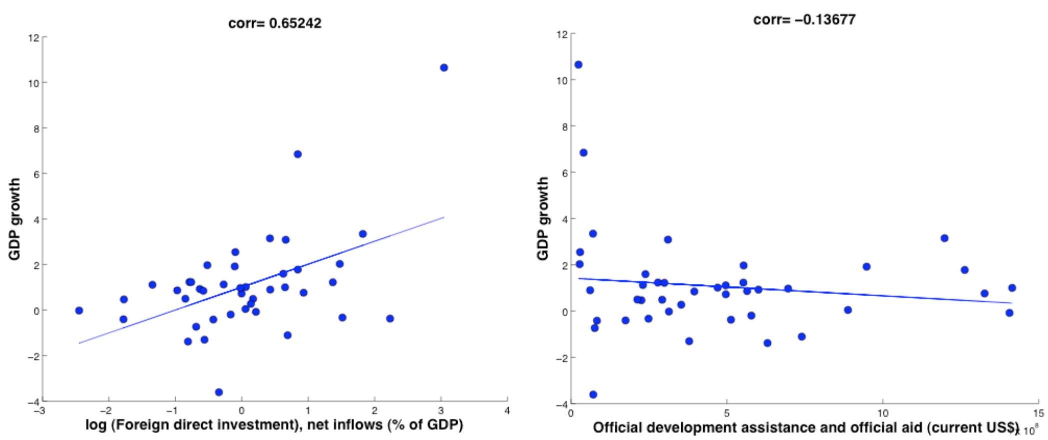

Figure 3. Scatter plot of GDP growth versus foreign direct investment (left) and official development assistance (right). Results indicate a slight positive association for FDI and a slight negative association for ODA.

If FDI is attracted to the countries with a facilitating environment for growth higher levels of FDI may serve as an indicator for those conditions. Analysis of FDI with other variables revealed a strong positive association with infrastructure. Both dam capacity and paved road density were positively correlated with FDI (Figure 4). In the case of dam capacity, the association is highly nonlinear, with a threshold effect whereby countries with significant (relative to others) dam capacity attract more FDI, while those without significant dam capacity attract much less. Additional dam capacity above a base level does not appear to affect the association. The SSI measure of storage exhibits a similar relationship with more storage relative to need associated with more FDI (Figure 5).

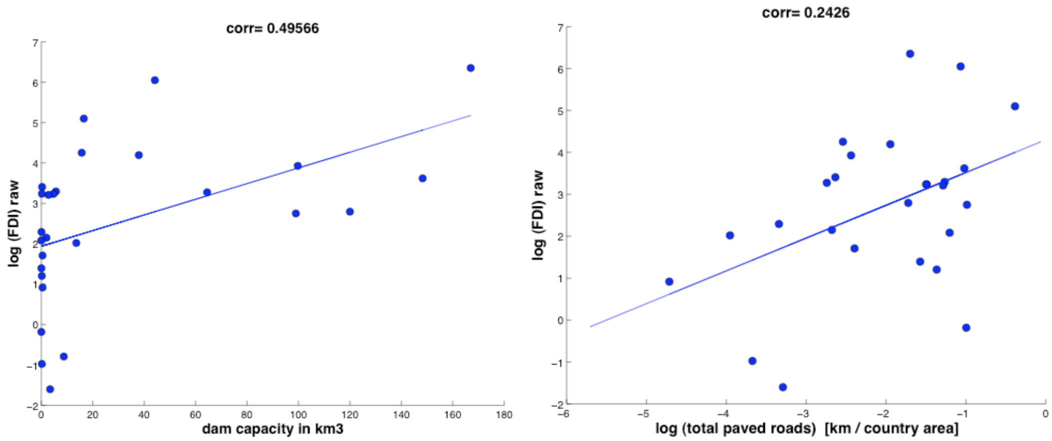

Figure 4. Scatter plots of log FDI versus dam capacity (left) and paved road density (right). These figures indicate a positive association between these infrastructure variables and FDI. The association between dam capacity and FDI exhibits a threshold effect, where all countries that have about 18 km^3 of dam capacity or more have relatively high FDI values.

In summary, the cross-country regression results for within SSA only are interesting for what was revealed and what was not. First, there were no strong associations between raw measures of infrastructure or institutions and economic growth. The homogeneity in SSA countries in each of these terms likely contributes to this lack of association. Second, the clear negative association between rainfall variability and economic growth is evident, despite the homogeneity of the countries of SSA. Next, the SSI measure of water storage is associated with increased rates of economic growth in SSA. Finally, there are clear associations between infrastructure and Foreign Direct Investment, and this may be an indication that infrastructure provides the platform needed for economic growth that Grey and Sadoff (2006) hypothesize.

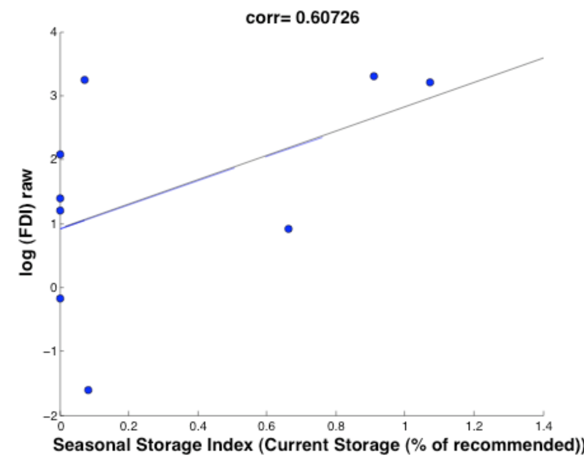

Figure 5. Scatter plot of log FDI versus SSI. The figure shows a positive association between FDI and water storage in these countries.

3. Design of a water security index.

In order to further explore the climate effect on economic growth on the countries of SSA, individual country regressions were performed using panel data. Economic growth was the dependent variable while an index of rainfall variability was used as the independent variables. Country average rainfall is often used to evaluate rainfall effects in econometric analyses. The spatial averaging over a country tends to reduce the variability of the actual rainfall experienced at a particular location and contributes to an underestimation of its effect. In place of country-averaged rainfall, the Weighted Anomaly Standardized Precipitation (WASP) index was used to quantify abnormal rainfall amounts (Lyon and Barnston, 2006). The WASP calculates deviations in monthly precipitation from their long term mean and then sums those anomalies weighted by the average contribution of each month to the annual total, according to the following formula:

$$S_N = \sum_{t=1}^{N} \left(\frac{P_i - \overline{P_i}}{\sigma_i} \right) \frac{\overline{P_i}}{\overline{P_A}} \qquad (1)$$

In (1) P_i and $\overline{P_A}$ are the observed precipitation in the *i*th month and the long term average precipitation for the *i*th month, σ_i is the standard deviation of monthly precipitation for the *i*th month and P_A is the mean annual precipitation. The number of months over which the index is calculated is indicated by N. We use $N = 12$ to capture annual precipitation anomalies. The WASP is designed such that rainfall anomalies are measured relative to the typical rainfall for a given month. The result is well correlated with drought indices, such as the Palmer Drought Severity Index. The WASP index is calculated on a gridded precipitation data set using data from 1945 to 2000 (New et al., 2000).

A final step is performed with the WASP index in order to account for spatial variability and for extreme anomalies that would be likely associated with droughts or floods. A threshold is set at -1 and +1 and the fraction of grid cells in each country that exceed either threshold is counted. This is calculated each year to produce timeseries of the fraction of land for each country that was categorized as drought (WASP < -1) or as flood (WASP > 1). These timeseries were then regressed against panel data for per capita GDP growth to assess the impact of rainfall variability on economic growth in each individual country.

The regressions were performed with per capita GDP as the dependent variable and the drought and flood WASP values as the independent variables. In regression, the significance of each independent variable is evaluated according to the Student's t statistic calculated from the regression coefficient associated with that variable. Higher t values indicated higher confidence that the regression coefficient has a magnitude of greater than zero. In this analysis, higher t values indicate more confidence that the independent variable, either drought or flood, has a significant effect on economic growth for a given country. Since the effect is negative, lower values (more negative) indicate a stronger deleterious effect, while higher values indicate a minor or positive effect. Thus, the t value is a potential indicator of water security. We adopt it here as a water security index and use it to draw inferences on the sources of water security that mark some countries and the vulnerability that others exhibit.

4. Results of Water Security Index Analysis

The water security index was calculated separately for drought effects and flood effects. While many countries are affected by significant negative impacts due to both, the characteristics of the most affected differ considerably between the two climate extremes. The ranking of SSA countries according to the t statistic-based water security drought index is shown in Table 1. The list is ordered from low to high according to the value of the water security index value. Thus, countries at the top of Table 1 exhibit the largest negative response in GDP growth to drought, while those at the bottom have the least negative response and are deemed most resilient to drought. Some inferences regarding water security can be made by dividing the tables into subgroups and comparing aggregate statistics of the countries in those groups. We term the values used to characterize these groups "resilience variables."

The list of countries in Table 1 is divided roughly into thirds. The upper third of Table 1 are the countries with the lowest value of the water security drought index and consequently are the most vulnerable to drought. Each of the countries in this group has a statistically significant negative correlation with drought, as the line for significance coincides with the cutoff for the upper third. The summary statistics for subgroups of the water security drought index are shown in Table 2. The table presents interest findings regarding the resilience statistics of countries that are more or less resistant to drought. First, countries that have large negative responses to drought tend to have less internal, renewable water resources on average. Presumably, due to a lower baseline amount of water, when a drought occurs the water availability likely dips below some minimum levels needed to support the economy. Also as expected, agriculture represents a larger percentage of a country's economy on average for countries that are more vulnerable to drought. Also, despite the negative return on investment that many irrigation schemes have yielded, the percentage of agriculture that is irrigated appears to contribute to water security. As shown in Table 2, countries in the bottom third of economic growth response to drought have on average a lower percentage of agriculture that is irrigated.

The status of water infrastructure as indicated by dam capacity is initially surprising.

Table 1. Water security drought index. Values are listed from lowest (least resilient) to highest (most resilient). The double line indicates statistical significance of the t value above that line.

Country Name	t statistic	IRWR	Dam capacity per capita	GDP per cap. (1981-2005)
Niger	-4.61	282	8.1	175
Cote d'Ivoire	-3.5	4,548	2,254.8	668
Eritrea	-3.34	652	21.9	188
Zimbabwe	-3.3	948	695.9	594
Sudan	-3.12	874	256.3	325
Nigeria	-2.92	1,739	347.4	352
Mauritania	-2.88	134	298.7	371
Zambia	-2.43	7,342	18,308.3	352
Togo	-2.17	2,292	341.0	261
Congo, Rep.	-2	58,146	2.4	1076
Uganda	-1.88	1,461	4,494.6	204
Guinea-Bissau	-1.84	10,403	-	167
Malawi	-1.8	1,308	3.5	144
Congo, Dem. Rep.	-1.69	16,539	-	159
Guinea	-1.46	26,218	218.3	350
Gabon	-1.24	121,392	162.8	4107
Benin	-1.17	1,489	5.8	298
Mozambique	-1.12	5,229	3,361.2	183
Equatorial Guinea	-0.9	51,282	-	1674
Lesotho	-0.87	2,906	1,087.2	415
Kenya	-0.84	638	125.8	424
Burkina Faso	-0.81	933	380.8	221
Botswana	-0.79	1,337	211.7	2353
Chad	-0.71	1,694	-	184
Ethiopia	-0.66	1,685	47.7	122
Liberia	-0.35	57,356	-	295
South Africa	-0.27	991	630.3	3158
Senegal	-0.12	2,553	154.8	415
Central African Republic	-0.01	36,043	-	262
Mali	0.03	4,475	1,015.4	198
Rwanda	0.24	613	-	251
Ghana	0.44	1,417	6,946.7	227
Madagascar	0.46	18,826	27.5	251
Gambia, The	0.66	2,052	-	320
Namibia	0.67	3,063	462.0	1805
Tanzania	1.05	2,230	111.4	264
Swaziland	1.08	5,634	540.2	1224
Angola	1.31	10,513	-	718
Cameroon	1.41	16,753	940.5	759
Sierra Leone	1.7	30,960	-	223

Countries that are more vulnerable to drought have a larger volume of dam capacity on average than countries that are more resilient. This counter intuitive result is likely a function of the low level of dam capacity in SSA, such that the countries that may have more capacity may still not have an adequate inventory to manage the variability that they face. As discussed in part 2, the need for storage is partially a function of hydrologic variability. Countries that are exposed to more drought may have invested in water storage, and thus have more water storage than countries that face less drought. However, that water storage may still be inadequate to mitigate the effects of drought. The SSI variable was designed to account for this factor and the results in Table 2 give credence to this explanation. Notice that the SSI value in the more vulnerable countries is much lower than in the more resilient countries. The SSI indicates the volume of water storage a country has as a fraction of a design storage value. Thus, although the countries that are more vulnerable to drought have more storage, that storage amount is a smaller fraction of the "ideal" amount. It should be noted however that the SSI is calculated for a smaller subset of countries in each group.

Other measures of infrastructure do not have any apparent effect, with the exception of phones. Countries that are more vulnerable to drought tend to have less phones. Phone penetration is well correlated with per capita GDP and since the more vulnerable countries also have lower GDP, this may be an extraneous correlation. However, it is also plausible that better communication links could provide society with information about drought that allows mitigative actions to be taken.

In summary, the results related to the water security drought index presented in Table 2 can be used to characterize resilience to drought. On average, countries that are more resilient to drought have economies with slightly lower percentage of agriculture, a higher percentage of agriculture is irrigated, higher per capita GDP, more internal renewable water resources, a higher SSI and slightly greater road density. Resilience variables that may not be indicative of water security, for the reasons cited above, are dam capacity and phone lines. These are associated with less resilience in the case of dam capacity and more in the case of phone lines, but are unlikely causative in either cause. The quality of institutions, as indicated by the Rule of Law variable, did not differ based on the water security drought index.

Table 2. Resilience Variables for water security drought index.

Resilience Variables	Mean	Lower Third (vulnerable)	Upper Third (resilient)
WSI drought	-0.99	-2.68	0.69
Mean per cap GDP (1981-2005)	643	360	532
Ag %	13%	14%	11%
Irrigation %	0.51	0.37	0.78
Rule of Law	-0.54	-0.61	-0.59
IRWR	12,874	7,619	10,395
Dam capacity per capita	1,087	1,931	784
SSI	0.26	0.01	0.24
Road Density	0.14	0.14	0.17
Phones	0.0097	0.0058	0.0081

The ranking of countries based on the water security flood index is shown in Table 3. The countries are ordered from low to high, with countries that exhibited strong negative responses of GDP growth to floods at the top of the table. As in the case of the water security drought index, countries were grouped into thirds representing more and less resilience to flood in order to draw inferences from the characteristics of each group. Table 4 shows the aggregate statistics for resilience variables according to each subgroup in the water security flood index. The characteristics are often the complement of the drought findings. The countries with stronger negative responses to flood tend to have a larger volume of internal renewable water resources, more irrigated agriculture and a lower percentage of agriculture as a fraction of GDP.

The results for the water security flood index are not as informative as the water security drought index. There are two reasons for this. The first is that in the regressions, the WASP flood index was on average a less informative predictor of economic growth than drought. The WASP flood index is calculated based on monthly precipitation values, while flood-inducing precipitation occurs on the order of days or possibly weeks. Therefore, the monthly averaging of precipitation conflates flood events with months that have above average, but not necessarily flood-inducing rainfall. The weak explanatory value of the WASP flood index indicates that it is probably not effectively identifying where flood effects are occurring. Also, on average the WASP drought index was more effective as an explanatory variable.

Table 3. Water security flood index. Values are listed from lowest (least resilient) to highest (most resilient). The double line indicates statistical significance of the t value above that line.

Country Name	t statistic	IRWR	Dam capacity per capita	GDP per cap. (1981-2005)
Congo, Rep.	-3.74	58,146	2.4	1076
Zambia	-3.31	7,342	18,308.3	352
Zimbabwe	-1.87	948	695.9	594
South Africa	-1.86	991	630.3	3158
Sudan	-1.74	874	256.3	325
Burkina Faso	-1.66	933	380.8	221
Swaziland	-1.51	5,634	540.2	1224
Senegal	-1.25	2,553	154.8	415
Togo	-1.24	2,292	341.0	261
Malawi	-1.19	1,308	3.5	144
Kenya	-1.14	638	125.8	424
Nigeria	-0.86	1,739	347.4	352
Central African Republic	-0.79	36,043	-	262
Eritrea	-0.75	652	21.9	188
Benin	-0.41	1,489	5.8	298
Botswana	-0.35	1,337	211.7	2353
Gambia, The	-0.21	2,052	-	320
Uganda	-0.2	1,461	4,494.6	204
Liberia	-0.17	57,356	-	295
Mali	-0.07	4,475	1,015.4	198
Madagascar	0.1	18,826	27.5	251
Guinea	0.13	26,218	218.3	350
Guinea-Bissau	0.13	10,403	-	167
Gabon	0.41	121,392	162.8	4107
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Congo, Dem. Rep.	0.58	16,539	-	159
Cameroon	0.84	16,753	940.5	759
Niger	0.85	282	8.1	175
Rwanda	0.9	613	-	251
Mozambique	0.95	5,229	3,361.2	183
Lesotho	1.09	2,906	1,087.2	415
Mauritania	1.14	134	298.7	371
Ghana	1.33	1,417	6,946.7	227
Namibia	1.42	3,063	462.0	1805
Angola	1.81	10,513	-	718
Cote d'Ivoire	1.92	4,548	2,254.8	668
Tanzania	2.12	2,230	111.4	264
Sierra Leone	2.42	30,960	-	223
Cameroon	1.41	16,753	940.5	759
Sierra Leone	1.7	30,960	-	223

Since the regressions are run together, the residual from the drought effect may be identified as the flood effect, leading to the values in Table 4 that tend to be the complement of the values in Table 2.

Table 4. Resilience variables of the water security flood index subgroupings.

	Mean	Lower Third (vulnerable)	Upper Third (resilient)
WSI flood	-0.20	-1.69	1.34
Mean per cap GDP (1981-2005)	643	743	478
Ag %	13%	9%	13%
Irrigation %	0.51	0.64	0.19
Rule of Law	-0.54	-0.63	-0.76
IRWR	12,874	9,741	7,322
Dam capacity per capita	1,087	1,556	1,190
SSI	0.26	0.22	0.46
Road Density	0.14	0.21	0.11
Phones	0.0097	0.0150	0.0072

5. Conclusions

This study investigated the effects of climate on economic growth in SSA and further explored the attributes that contribute to some countries being more resilient than others to two extreme climate conditions, droughts and floods. There are several interesting findings. The cross country regressions reveal some general findings within the countries of SSA. Climate variability appears to have a negative influence on economic growth rates and level within the countries of SSA. This is a surprising result, given the homogeneity of the countries and the expected influence of other factors, such as governance. Nonetheless, the data indicate that even within this subset, climate variability matters. Next, the data indicate that foreign direct investment (FDI) is associated with infrastructure. This is important because FDI is also associated with economic growth rates. This may imply that infrastructure provides the context to attract FDI and engender economic growth. Infrastructure was not found to be associated with increasing economic growth. However, when water storage was adjusted based on the demand for water and hydrologic variability, in the form of the SSI, there was an association between a greater percentage of the design infrastructure value and economic growth.

Individual country regressions were used to specify the degree to which climate anomalies affected economic growth in those countries. The results of these regressions were used to create a water security index for flood and drought effects. The water security drought index provides a revealing indication of the characteristics that contribute to resilience or vulnerability to droughts. Among the attributes that are associated with greater resilience are more internal renewable water resources, a lower percentage of agriculture as a contributor to GDP, and a higher rate of irrigation as a percent of agricultural area. The water security flood index was less informative, largely as a result of the index used to specify flood events. While monthly precipitation values are appropriate for identifying droughts, they do not appear to capture flood impacts. Unfortunately, there is a lack of historical flood data that could be used to estimate the economic impact of floods on economic growth in SSA. As a result, that impact is surely underestimated.

NOTE: The work described in this paper is the result of contributions from a team of researchers. The contributors are Robyn Meeks, Kenneth Hunu, Daniela Domeisen, Winston Yu, Claudia Sadoff, David Grey and James Hansen. This work is partially funded by the World Bank, Bank Netherlands Water Partnership Program, and NOAA.

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