# An Analysis of Water Scarcity-induced Cereal Grain Import

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**Abstract:** The paper analyzes the relationship between water scarcity and cereal grain import, using the country level data available from various international organizations and institutions. A multiple regression model is applied for the analysis. Five-year running averages of six pre-selected variables over 1980-1999 were used to capture changes in the effects of water related factors on cereal import dependence. A water scarcity threshold of about 2000 $m^3$/capita is identified. Below the threshold a country's cereal import is inversely related to the amount of its water resources. Above it, no significant relationship is discernable. The analysis also reveals that the impact of water scarcity on cereal import dependence has been intensifying over the years due in part to the decline of water resources in relation to the population. There is a strong positive relationship between the level of income and the amount of cereal import. Expanding irrigated areas in water scarce countries is significant for improving food self-sufficiency, whereas relationship between non-cereal agricultural import and cereal import is rather weak. The aggravation of water scarcity and the rigid expansion of food demand in association with the population growth have been rapidly escalating the scale of water scarcity induced food import and the magnitude of food insecurity worldwide. Slowing down the population growth and establishing a healthy world water-food regime are crucially important for meeting the challenges in the years ahead.

**Keywords:** Water scarcity; Cereal import; Modeling

## 1. INTRODUCTION

Water and food are the fundamental elements for the survival of mankind. With agriculture as the largest user of water, there is an inherent relationship between a country's available water resources and the capacity of food production. In many parts of the world, lack of water has been rapidly translated into constraints for food production. Most vulnerable are countries with unfavorable climatic conditions and high rates of population growth. To cope with the rigidly augmenting food demand while water stress is intensifying, many countries have opted for importing food from the international market. Of the food imported, cereal grains are predominant in terms of both quantity and the importance for food security to the importing countries.

Importing food from outside reduces water demand for local production of food. For water scarce countries, therefore, food import is virtually equivalent to importing water. The water embedded in such food imports has been termed by Allan [1997] as 'virtual water'. Cereal grains, as the dominant food commodities, have been the major carriers of virtual water. They played an important role in the water balance of the countries concerned [Zehnder, 1997].

This study examines the relationship between water scarcity and cereal import dependence. Physical water resources and factors affecting a country's capacity to utilize the resources are elaborated. Countries in Asia and Africa are used for the analysis. During 1998-1999, the annual net cereal grains imported into the two continents amounted to 116 million tons, absorbing all the surplus of the rest of the continents [FAO, 2001]. The two continents are also home to a majority of the people who live under constant food insecurity and poverty. Many countries are enduring water scarcity either because of the limited water resources, or lack of the capacity to bring the water into use, or both.

Recognizing the constraint of water scarcity on food production, however, does not render to a conclusion of the more water the better. Intuitively, one would expect that when the volume of available water resources exceeds a certain level, it would no longer be a limiting factor for agricultural production. In some cases, too much water may even cause adverse impacts, for example the cases with flooding and water logging. Hence, it is reasonable to conjecture that there is a threshold of water resources, below which a country's dependence on food import is inversely related to its water resources. Above this level, food import has no significant relationship with the water availability in a country. Along this line, three questions are raised. First, where is the threshold of water resources? Second, for the countries where water resources are below the threshold, how is the cereal import dependence related to water scarcity? And third, what are the differences in the factors affecting cereal import between water scarce and non-scarce countries?

Applying multiple regression modeling techniques, this study attempts to answer the above questions. A dynamic perspective is taken in the analysis of the relationship between water scarcity and cereal import dependence and the changes over time. We tested the hypothesis $H_0$ = there is a threshold of water resources below which a country's cereal import dependence is a function of the magnitude of available water. We refer to these countries as "water-scarce countries" and the threshold as the "water scarcity threshold". Above that water scarcity threshold, there is no direct relationship between the amount of available water and cereal import.

## 2. MODELING THE RELATIONSHIP BETWEEN WATER SCARCITY AND CEREAL IMPORT

We formulated the multiple regression model as follows. Net cereal import per capita (*Cereal*) was used as the dependent variable. This figure included both purchased cereals from the international market and food aid received from outside donors. The independent variables consisted of indicators for renewable internal and external fresh water resources per capita (*Water*), arable land per capita (*Land*), gross national product per capita (*GNP*), percentage of irrigated areas to total arable land modified by multiplying by the energy consumption per capita (*Irrig*), and the ratio of non-cereal agricultural import to export value (*I/E*). Sources of the above data are as follows: Freshwater data are from the World Resources Institute [2000]. Data for GNP/per capita are from the World Bank [2000]. Energy consumption per capita data are from Energy Information Administration [2001]. All other data are from FAO [2001]. In addition, a nominal scale variable (*Region*) was also included to account for the differences between Sub-Saharan African countries and others. Based on our preliminary analyses, this grouping was necessary due to rather different statistics of the above variables for Sub-Saharan countries.

In the regression analyses, we tested different combinations and formations of variables to find the best fit of the model.[1] The multiple regression model used in the final analysis was expressed as follows:

$$Cereal = a + b_1\,Water + b_2\,Land + b_3\,GNP + b_4\,Irrig + b_5\,I/E + b_6\,Region \qquad (1)$$

Where,
*Cereal* = volume of per capita cereal import plus per capita cereal aid; kg/capita;
*Water* = per capita annual freshwater resources, $m^3$/capita, year;
*Land* = per capita arable land resources; ha/capita;
*GNP* = GNP per capita at the 1995 constant price; US$/capita;
*Irrig* = percentage of irrigated areas in total arable land multiplied by energy consumption per capita;
*I/E* = ratio of import value to export value of non-cereal agricultural products;
*Region* = Regional dummy variable. South Saharan countries are assigned a value of 1 and the rest of the countries are 0;
*a* = the regression constant, and;
$b_1$ through $b_6$ = the regression coefficients.

As both cereal production and import volumes fluctuated significantly from year to year, five-year running averages of all variables were calculated using the data from 1980 to 1999 (i.e., 1980-1984, 1981-1985, ...., 1995-1999). This resulted into 16 data periods, for which we performed three different regression analyses: all the countries in Asia and Africa, the countries with physical water resource scarcity and, the countries with no scarcity of physical water resources. The running five-year averages calculated as above provided us with a smoothed set of data, mitigating the effects of factors such as annual cereal stock exchanges and weather fluctuations. The statistical

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[1] We also tested the logarithmic form of the physical water resources and ranked physical water resources in the regression.

significances of the variables were obtained through calculation of the students' t statistics.

The regression started from the latest period 1995-1999, and included all the countries in Asia and Africa. We calculated the coefficients in the model as well as the significance factors for the 16 time periods. We then gradually excluded countries in a descending order with reference to their water resource figures. At around 2000 $m^3$/capita, we obtained the highest $R^2$ value. Further exclusion of countries in accordance to water resource figures yielded deteriorating $R^2$ value and variable significance in the model. We therefore took 2000 $m^3$/capita as a threshold value of water resources to separate all the countries into two: water resource scarce and non-scarce countries. The information pertaining to the 25 countries with water resources less than 2000 $m^3$/capita is provided in the Appendix. As mentioned earlier, during the last two decades the population has expanded rapidly in most of the countries considered. The physical water resources on per capita basis have been shrinking accordingly. As a result, some countries where physical water resources were around 2000 $m^3$/capita in the 1995-1999 period had a higher figure of up to 2800 $m^3$/capita in the early 1980s. For the time periods prior to 1995-1999 we used the same 25 countries in our regression analysis as we had obtained for the 1995-1999 period. The reason for this was, firstly, to obtain a set of consistence regression coefficients for trend analysis, and secondly, to allow for the transient change in the water scarcity threshold.

Table 1 and Table 2 present a summary of the regression results for the groups with water resources below and above 2000 $m^3$/capita, respectively. The t-statistics depict the importance of each variable. Positive t-values indicate a direct correlation, while negative values depict an inverse correlation. The trend and significance of the variables in the tables show distinct differences for the countries with water resources below and above 2000 $m^3$/capita, indicating the significant differences in the two groups. It is also noticeable that while the regression mode in (1) describes well the variation in cereal import for the countries with water below 2000 $m^3$/capita, it does not account significantly for the same variation for countries with water above 2000 $m^3$/capita. Since the focus of our analysis is on the water scarce countries, we did not try to further model the later and the results for non-water scarce group are only used for comparison.

For the group of the countries with water below 2000 $m^3$/capita, $R^2$ ranges between 0.75 and 0.85 for all the sub-periods, suggesting a good and stable explanatory power of the model. Most of the coefficients are significant at the 5 percent level. In the group with water above 2000 $m^3$/capita, in contrast, $R^2$ value ranges between 0.3-0.5, and fewer coefficients of variables are statistically significant, indicating that there are other important factors not included in the current model. Thus, the model has a relatively lower fitness for this group of countries. Noting that most of the countries in this group are Sub-Saharan countries, high political instability, civil and border wars in many of them would have been largely responsible for the poor performance of agricultural production.

## 3. INTERPRETING THE RELATIONSHIP BETWEEN WATER SCARCITY AND CEREAL IMPORT DEPENDENCE

### 3.1 Physical Water Resources and Cereal Import Dependence

In the group with water resources below 2000$m^3$/capita, *Water* variable is statistically significant at above 5 percent significance level for almost all the periods (Table 1). The negative sign of the coefficient means that the lower the physical water resources, the higher the level of dependence on the cereal import in the domestic cereal supply. The significance of *Water* increases over time. The trend suggests that as per capita water resources decline, the effect of water stress on a country's cereal import dependence increases. This is consistent with our expectation. The t-value for *Water* is around 3.3 for the most recent period, which is well above the critical t-value of 2.06 for the 95% confidence level. The coefficient of -0.077 for *Water* in the latest period means that for every 100-$m^3$ decrease per capita of water resources, an 7.7 kg increase in per capita import must be born by the water-scarce countries. Assuming that this ratio remains constant in the next 20 years and the decrease in water resources is only due to population increase, then by the year 2020 the countries in the water scarce group will have to increase the cereal import by an average of 20-30 kg/per capita merely to cope with the population growth and the associated decline in per capita water resources. A population growth rate of 2 % of these countries would translate to approximately $7.5x10^7$ tons of increased cereal demand. This figure is highly conservative, as the increase in water demand from other sectors of the national

**Table 1.** A summary of the regression statistics for water scarce countries (Water resources < 2000 $m^3$/capita).

| Time period | | Constant | I/E | GNP | Land | Irrig | Water | Region | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 1980-1984 | Coefficient | 164.2 | 2.422 | 0.016 | -17.90 | -0.0009 | -0.038 | -91.59 | 0.74 |
| | t-value | 2.0 | 1.080 | 2.510 | -0.16 | -2.0535 | -1.705 | -2.27 | |
| 1981-1985 | Coefficient | 148.3 | 3.067 | 0.020 | -14.79 | -0.0009 | -0.035 | -82.06 | 0.77 |
| | t-value | 1.9 | 1.495 | 3.179 | -0.13 | -2.6776 | -1.582 | -2.06 | |
| 1982-1986 | Coefficient | 140.8 | 2.876 | 0.022 | 30.75 | -0.0008 | -0.039 | -82.09 | 0.78 |
| | t-value | 1.7 | 1.421 | 3.403 | 0.26 | -2.7762 | -1.660 | -1.98 | |
| 1983-1987 | Coefficient | 151.6 | 2.040 | 0.021 | 48.95 | -0.0006 | -0.045 | -86.75 | 0.76 |
| | t-value | 1.8 | 1.004 | 3.204 | 0.38 | -2.5243 | -1.827 | -2.03 | |
| 1984-1988 | Coefficient | 168.8 | 1.015 | 0.020 | 54.17 | -0.0005 | -0.048 | -99.84 | 0.77 |
| | t-value | 2.1 | 0.508 | 3.383 | 0.43 | -2.6530 | -2.058 | -2.47 | |
| 1985-1989 | Coefficient | 178.4 | 0.672 | 0.018 | 39.03 | -0.0004 | -0.048 | -112.52 | 0.78 |
| | t-value | 2.3 | 0.378 | 3.241 | 0.31 | -2.5835 | -2.116 | -2.92 | |
| 1986-1990 | Coefficient | 187.5 | 0.505 | 0.015 | -72.61 | -0.0003 | -0.039 | -111.11 | 0.79 |
| | t-value | 2.5 | 2.165 | 2.722 | -0.53 | -2.2451 | -1.762 | -3.08 | |
| 1987-1991 | Coefficient | 183.5 | 0.835 | 0.014 | -97.11 | -0.0003 | -0.036 | -106.13 | 0.80 |
| | t-value | 2.5 | 2.547 | 2.617 | -0.72 | -2.3827 | -1.644 | -3.04 | |
| 1988-1992 | Coefficient | 179.7 | 1.023 | 0.012 | -63.31 | -0.0002 | -0.039 | -96.37 | 0.78 |
| | t-value | 2.5 | 2.434 | 2.441 | -0.47 | -2.2394 | -1.757 | -2.79 | |
| 1989-1993 | Coefficient | 178.2 | 1.684 | 0.010 | -55.58 | -0.0002 | -0.039 | -93.48 | 0.76 |
| | t-value | 2.3 | 2.639 | 1.973 | -0.37 | -1.7089 | -1.598 | -2.53 | |
| 1990-1994 | Coefficient | 172.9 | 2.051 | 0.010 | -9.91 | -0.0002 | -0.044 | -89.60 | 0.71 |
| | t-value | 2.0 | 1.881 | 1.793 | -0.06 | -1.3064 | -1.574 | -2.15 | |
| 1991-1995 | Coefficient | 210.4 | -1.910 | 0.015 | 91.15 | -0.0002 | -0.074 | -108.22 | 0.75 |
| | t-value | 2.6 | -0.935 | 3.011 | 0.62 | -1.9883 | -2.787 | -2.79 | |
| 1992-1996 | Coefficient | 219.6 | -2.225 | 0.016 | 51.48 | -0.0002 | -0.076 | -107.12 | 0.79 |
| | t-value | 2.9 | -0.960 | 3.396 | 0.36 | -1.9574 | -2.945 | -2.92 | |
| 1993-1997 | Coefficient | 221.1 | -2.024 | 0.016 | 39.64 | -0.0002 | -0.078 | -114.84 | 0.81 |
| | t-value | 3.0 | -0.871 | 3.664 | 0.27 | -1.8715 | -2.964 | -3.12 | |
| 1994-1998 | Coefficient | 232.0 | -2.633 | 0.017 | 1.33 | -0.0002 | -0.082 | -117.20 | 0.84 |
| | t-value | 3.3 | -1.121 | 4.004 | 0.01 | -1.8481 | -3.299 | -3.42 | |
| 1995-1999 | Coefficient | 206.7 | 1.382 | 0.019 | -48.55 | -0.0012 | -0.077 | -93.464 | 0.89 |
| | t-value | 4.9 | 0.625 | 4.863 | -0.41 | -1.606 | -3.440 | -3.009 | |

economy will pose further pressure on the availability of water for agriculture, particularly for staple food production. Water pollution will further exacerbate the problem. Water scarcity induced cereal import, therefore, can only become greater. Compounding this sober situation is the growth in the population elsewhere, especially the poorer countries. As more countries will be added on the list of water scarce group, the scale of water scarcity induced cereal import is bound to escalate.

In contrast to the physical water scarce countries, the coefficient of water resources in the group with water resources above 2000 $m^3$/capita (Table 2) is statistically insignificant for all the periods analyzed. The results suggest that water resources have no significant relationship to the cereal import in these countries.

The significantly different statistics for variable *Water* in the water scarce and non-scarce groups strongly suggests that 2000 $m^3$/capita is an approximate threshold of water resources. Below which, physical water resources are an important limiting factor to cereal production. Water scarcity-induced cereal import occurs. It is interesting to note that this volume of water is very close to the threshold of 1700 $m^3$/ capita suggested by Falkenmark and Widstrand [1992].

**Table 2.** A summary of the regression statistics for non-water scarce countries (Water resources > 2000 $m^3$/capita).

| Time period | | Constant | I/E | GNP | Land | Irrig | Water | Region | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 1980-1984 | Coefficient | 28.6 | 6.114 | 0.005 | -48.55 | -0.0006 | -6.5E-05 | 26.99 | 0.47 |
| | t-value | 0.6 | 4.336 | 1.606 | -1.49 | -0.6715 | -0.60882 | 1.69 | |
| 1981-1985 | Coefficient | 26.0 | 7.222 | 0.005 | -29.90 | -0.0009 | -8.6E-05 | 27.31 | 0.47 |
| | t-value | 0.5 | 4.603 | 1.625 | -0.85 | -0.8860 | -0.74422 | 1.60 | |
| 1982-1986 | Coefficient | 28.5 | 8.224 | 0.004 | -26.85 | -0.0010 | -9.5E-05 | 22.32 | 0.41 |
| | t-value | 0.5 | 4.071 | 1.392 | -0.65 | -0.8943 | -0.69273 | 1.15 | |
| 1983-1987 | Coefficient | 31.0 | 9.621 | 0.004 | -16.58 | -0.0010 | -0.00011 | 13.97 | 0.35 |
| | t-value | 0.5 | 3.626 | 1.051 | -0.34 | -0.8528 | -0.6882 | 0.62 | |
| 1984-1988 | Coefficient | 30.9 | 9.092 | 0.003 | -11.95 | -0.0009 | -9.8E-05 | 11.10 | 0.31 |
| | t-value | 0.4 | 3.290 | 0.933 | -0.22 | -0.7353 | -0.54513 | 0.46 | |
| 1985-1989 | Coefficient | 32.8 | 10.291 | 0.002 | 2.14 | -0.0007 | -0.00011 | -1.93 | 0.25 |
| | t-value | 0.4 | 2.592 | 0.413 | 0.04 | -0.5262 | -0.5748 | -0.07 | |
| 1986-1990 | Coefficient | 36.2 | 4.072 | 0.003 | -9.33 | 0.0002 | -0.00006 | 1.97 | 0.21 |
| | t-value | 0.5 | 1.665 | 0.841 | -0.16 | 0.1579 | -0.32021 | 0.08 | |
| 1987-1991 | Coefficient | 35.5 | 2.064 | 0.003 | -21.41 | 0.0006 | -4.5E-05 | 10.46 | 0.23 |
| | t-value | 0.6 | 1.458 | 1.029 | -0.41 | 0.5511 | -0.26048 | 0.48 | |
| 1988-1992 | Coefficient | 31.1 | 1.127 | 0.003 | -30.49 | 0.0008 | -2.4E-05 | 20.62 | 0.28 |
| | t-value | 0.6 | 1.380 | 1.209 | -0.66 | 0.8633 | -0.15348 | 1.09 | |
| 1989-1993 | Coefficient | 27.9 | 0.724 | 0.003 | -35.88 | 0.0007 | -9.3E-06 | 25.05 | 0.34 |
| | t-value | 0.6 | 1.412 | 1.517 | -0.87 | 0.9890 | -0.06754 | 1.53 | |
| 1990-1994 | Coefficient | 24.7 | 0.469 | 0.003 | -49.46 | 0.0007 | -9.4E-06 | 34.40 | 0.41 |
| | t-value | 0.6 | 1.104 | 1.947 | -1.36 | 0.9824 | -0.07744 | 2.36 | |
| 1991-1995 | Coefficient | 26.8 | 0.212 | 0.004 | -67.67 | 0.0006 | -7.1E-06 | 38.85 | 0.43 |
| | t-value | 0.6 | 0.689 | 1.998 | -1.77 | 0.9565 | -0.0556 | 2.68 | |
| 1992-1996 | Coefficient | 28.1 | 0.199 | 0.004 | -72.27 | 0.0005 | -1.5E-05 | 38.16 | 0.43 |
| | t-value | 0.7 | 0.643 | 2.173 | -1.82 | 0.6657 | -0.10983 | 2.60 | |
| 1993-1997 | Coefficient | 43.9 | 0.074 | 0.002 | -130.42 | 0.0012 | -4.1E-05 | 40.40 | 0.59 |
| | t-value | 1.0 | 1.716 | 1.576 | -5.56 | 3.2381 | -0.29198 | 2.85 | |
| 1994-1998 | Coefficient | 45.1 | 0.235 | 0.003 | -129.52 | 0.0009 | -4.7E-05 | 39.08 | 0.56 |
| | t-value | 1.0 | 0.639 | 1.917 | -5.56 | 2.3473 | -0.32788 | 2.77 | |
| 1995-1999 | Coefficient | 44.5 | 0.434 | 0.003 | -133.82 | 0.0073 | 0.0000 | 38.192 | 0.56 |
| | t-value | 3.3 | 0.950 | 2.052 | -5.79 | 1.9258 | -0.2286 | 2.709 | |

### 3.2 Arable Land Resources and Cereal Import

In the group of water scarce countries, the variable *Land* is statistically insignificant for all the periods. This may imply that in water scarce countries, land is not a major limiting factor for cereal production. In many arid and semi-arid areas, irrigation is crucial in determining the productivity of land. For this reason, the effect of land may be partly captured by the irrigation variable in the regression.

In contrast, *Land* in the water abundant group is statistically significant in the later periods. The increasing significance of *Land* may partly be related to the population growth, and consequently the decline in per capita arable land base. Like water resources, the decline in land resources has become an increasing constraint to cereal production.

### 3.3 The Socio-economic Aspects of Water Scarcity and Cereal Import

For the countries in the water scarce group, the coefficient of GNP per capita is statistically significant for all the periods. The positive sign of the coefficient means that the increase in GNP per capita will lead to an increase in cereal import. On average, every US$100 of increase in GNP would result in 2 kg of increase in cereal import, holding all other factors constant.

The ratio of irrigated areas to total arable land multiplied with per capita energy consumption (*Irrig*) is also statistically significant. The negative sign of the coefficient means that bringing more arable land under irrigation reduces a country's cereal import dependence. Again, this is consistent with our expectation.

The ratio of non-cereal agricultural import to export value (*I/E*) has a direct relationship with cereal import, but it is statistically insignificant for most of the periods. The results suggest that there is no trade substitution between non-cereal agricultural import and cereal import in water scarce countries. This is more or less contrary to the prior expectation that the shift to higher-value crops for export could finance cereal import.

## 4. CONCLUDING REMARKS AND RESEARCH OUTLOOKS

The regression results strongly support the hypothesis that a country's water resources are an important factor in shaping its cereal import status. Per capita water of 2000 $m^3$/year is an approximate threshold of water resources. Below this volume, a country's food production is constrained by the lack of water resources. Cereals have been imported to compensate the water scarcity. The regression results also show that the effect of water scarcity on cereal import dependence has been intensifying over the years. The rapid population growth has been largely responsible for the intensification by shrinking the per capita water availability.

This study is a novel attempt to quantitatively analyze the water-food relationships taking into account the social and economic aspects of water scarcity. There are inevitably shortcomings. For example, in the study the physical water resources per capita did not distinguish the water from shared sources, such as international rivers and lakes. This shortcoming may be ameliorated with the application of more detailed data at the water basin level.

The study attempted to mitigate the effect of temporal and spatial variations of water resources by counting the irrigation coverage in relation to total arable land. The effect may nevertheless be significant. The ignorance of climate conditions is also a drawback. Furthermore, our water resource figures are limited to 'blue' water. As Savenije [2000] argued, however, 'green' water, or the soil water, makes an important contribution to the global food production. In our study, the green water is not specified explicitly, though embodied implicitly by the domestic production capacity.

Part of the above-mentioned shortcomings has stemmed from the fact that there is no best indicator that can appropriately reflect the complexity of water scarcity. For this reason, it is of significance to construct a comprehensive indicator of water scarcity that takes into consideration the physical, social and economic aspects of water resources. When such indicator is constructed, the relationship between water scarcity and food import dependence may be better interpreted.

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