

## ***Interactive comment on “The question of Sudan: a hydroeconomic optimization model for the Sudanese Nile” by S. Satti et al.***

**Anonymous Referee #2**

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This paper presents a model that is applied to evaluate the optimal allocation of water resources to the hydropower and irrigation sectors in the Sudanese portion of the Blue Nile. The response of the model to changes in economic conditions and to the volume and timing of hydrologic flows is analyzed. The main result is that upstream regulation leads to increased irrigation withdrawals in Sudan only under the condition that there is a drop in the price of electricity in Sudan, otherwise the optimal development path is to increase hydropower production.

Major comments.

1. My main concern is with the hydro-economic model and, more specifically, with the method used to assess the contribution of irrigated agriculture to the system-wide ben-

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efits. Due to data limitations, the authors assume that the net benefits correspond to (crop price \* production\*AGM). This formulation overestimates the value of water as the contribution of the other inputs (fertilizer, land, etc) to the production of the agricultural goods is ignored. For the energy sector, the net benefits are given by price\*hydropower where hydropower is a function of the head and the turbined outflow, which properly reflects the contribution of water. For a study emphasizing the economically efficient allocation of water, it is key that the marginal value of water in both sectors be treated on the same footing.

2. This study considers that all irrigation schemes in Sudan are supplied by the Blue Nile, which is not correct. There are schemes on the White Nile and the Atbara. So, the upper bound on maximum irrigation withdrawals must be corrected (eq 5).

3. In the '59 agreement, Sudan is entitled with 18,5 BCM/year, which includes both irrigation withdrawals and evaporation losses from reservoirs. So, eq. 5 must be changed accordingly.

4. The optimization model (1)-(8) is deterministic. The authors therefore assume perfect foresight over a period of 20 years. They should discuss the impact of this assumption on the results.

5. I have some serious concerns about some key parameters/equations used in the model:

5-1. Equation 2. This is supposed to be the hydropower production function. A close examination reveals that the units on the right-hand side do not correspond to energy (KWh). As a matter of fact, with  $rhe = (m^3)$  (“amount of water passing...”page 11574, line 25),  $h = (m)$  and  $effh = (-)$ , the product gives  $(m^4)$  not (kWh). In the appendix, “rhe” has become a flow (eq. A4) not a volume. Please clarify. Also, what is the “efficiency of the dam” (effh)? I hope that this is not the efficiency of the power plant because the value of 0.5 would then be extremely low (and would favor the irrigation sector). Typical efficiencies for a hydropower station range between 0.8-0.9. It is suggested that the

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authors use the classic hydropower production function which depends on the head, the flow, the density of water, the efficiencies of the turbines and the alternators, the acceleration of gravity, etc. It can be found in any good textbook in water resources engineering.

5-2. Crop yield (table 1). 1 ton/ha for wheat in an irrigated scheme seems very low. See recent Msc Thesis "Land and water productivity of cash and food crops in Gezira scheme" by Mohamed Osman, University of Gezira (2009) for more realistic yields in the region.

5-3. An irrigation efficiency of 0.8 is way too high. This might be the official figure from the Sudanese government but studies have shown that this is grossly overestimated. See Msc Thesis "Irrigation performance of Gezira scheme in Sudan..." by Thiruvarduchelvan, UNESCO-IHE (2010)

5-4. Crop price (Table 1). Are those the farmgate prices? What are the sources? 5. Electricity price (Table 1). The authors should explain how the price of electricity is determined (and to what it corresponds). Please provide a reference.

Other comments 1. Some comments on spelling/sentence structure etc (please note that the list below is not exhaustive and the paper should be re-read and refined).

(a) P11567L22 change "though external influences..." to "through external influences..."

(b) P11570L23 mentions "human infrastructure". Human infrastructure relates to things such as health, education, nutrition etc. This should read "infrastructure" only.

(c) Some sentences are awkward and difficult to read. For example P11572L9-17 which reads "The model produces distribution functions for dam geometry, evaporation loss and irrigation intended to inform dam management policies." is awkward. In Goor et al., the hydro-economic model does not produce distribution functions for dam geometry. Allocation decisions can be presented in the form of distribution functions. P11582L24-26 reads "Egypt might view movement to the right on the chart –

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increasing irrigation withdrawals – as a potential threat to water resources in the absence increased Nile river flow or counterbalancing shared benefits." This is difficult to understand and should read "Egypt might view movement to the right on the chart – increasing irrigation withdrawals – as a potential threat to water resources in the absence of increased Nile river flow or the counterbalancing of shared benefits."

(d) P11572L9 change "...economic benefits for all players more than double..." to "...economic benefits for all players more than doubled..."

(e) P11573L16 change "whilst" to "while"

(f) P11576L14 reads "The storage at each dam location must be equal to a simple water balance". This should be "The storage at each dam location can be calculated using a simple water balance."

(g) You have used the words dam and reservoir interchangeably. They are not interchangeable. The dam is the barrier that creates the reservoir. For example, P11576L14-16 reads "The storage at a particular time step is the total water contained in the dam in the previous time step plus the water entering each dam minus what comes out of the dam through upstream flow." In this sentence the word dam should be replaced by the word reservoir.

(h) P11570L5-6 reads "The dams also supply various schemes in Rahad Suki as well as upstream and downstream of Sennar...". This should be "The dams also supply various schemes in Rahad and Suki as well as..."

(i) P11570L24-28 reads "They are particularly valued in complex water management problems because they can inform a dynamic analysis of water resources and needs that guides basin managers...". The use of the word inform is incorrect in this sentence. This should read "They are particularly valued in complex water management problems because they provide a dynamic analysis..."

(j) P11572L19-20 reads "...calculates the economic benefit of development and

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changes to the climate to upstream portions of the Blue Nile.” This should read “calculates the economic benefit of proposed development under changing climatic conditions.”

2. When referring to another section of the paper use “See section N.NN” format. For example, P11570L21 reads “(see irrigation constraints)”. This should be changed to “(See section 2.1.3 on irrigation constraints)”. There are other instances like this. Please validate and change all instances.

3. In tables 1 and 2, please validate the units. Area = Area irrigated = m<sup>2</sup>/month ? Since, in the equations, the variables are all dependent on location (l), month (m) and year (y) it is then confusing, and unnecessary, in table 2 to define units as something per month.

4. A comparison of presented results with those from other/similar studies should be included:

a) McCartney et al., Evaluating the downstream implications of planned water resource development in the Ethiopian portion of the Blue Nile River, Water International, 2012

b) Arjoon et al, Hydro-economic risk assessment in the eastern Nile River basin, Water Resources and Economics, 2014

5. Please ensure that all statements that need to be referenced are referenced. For example: P11585L9-11 reads “The GERD, for example, is expected to generate electricity that can be sold at about half the price of existing Sudanese facilities, and the dam will be connected to the Sudanese grid.” This should be referenced.

6. On P11570 in the paragraph in which the various dams in Sudan are described, the size and capacity of the dams are mentioned, except for Merowe (last 3 sentences in the paragraph). This information should be added.

7. On P11579-11580 it states “There is a significant connection between dry periods and hydropower release at Roseires. This is illustrated by a reduction in Hydropower

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release during the periods of dry annual flows (months 70-120 and months 190-240), and higher hydropower release during wet periods (Fig. 3c).” First, hydropower should not be capitalized. More importantly, in figure 3c we see a range of hydropower releases for the 3 dams. For Roseires, the high release is maximized at around 2500 million m<sup>3</sup>. There is a variation in the low release. I suspect that it is this variation in low release that is discussed in the sentence. In other words, “This is illustrated by lower hydropower releases during the periods of dry annual flows than during the wet flow periods.”

8. On P11575L19 it states “...dependent on the water content for each crop type, at a specific month in a particular year.” Water content should be changed to water requirement.

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