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Valuing Water Recharge in the Face of Damming the *Farin Ruwa* Wetlands for Electricity Generation in the Benue Trough of Central Nigeria

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Author's contribution

This work was carried out by the author IGU. He designed the study, wrote the protocol, and the first draft of the manuscript. He managed the literature searches, supervised and analysed the field survey as well as the tube well experimental process. The author read and approved the final manuscript.

Research Article

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ABSTRACT

Nasarawa, a state authority in Nigeria has planned a hydro-electric dam upstream of Farin Ruwa wetlands which has the potential of directly disrupting the natural flow of the Farin Ruwa River and by extension the Dep river system in the Benue trough. It is therefore important not only to identify this potential but to quantify it in economic terms so as to serve as a basis for policy to protect the environment. Data on dry-season farming were sourced from irrigated floodplain farmers occupying an area of 2,500 ha. From the data collected, an economic valuation of per hectare agricultural production of irrigated land was conducted. The survey was conducted around the Farin Ruwa segment of the Dep river system in Nasarawa State of Nigeria between September and December 2009. Using two welfare change measures, it valued the recharge function based on estimated production functions and assumed changes in groundwater recharge and levels. The study found out that that irrigation agriculture using water from the shallow groundwater aquifer was 41,233 Naira (US$ 278.6) per hectare and the total potential welfare loss for the whole wetlands as a result a potential drop in groundwater levels by 1m in depth due to the damming of the Dep river system was 1,062,832,391.06 Naira (US $ 7,181,299.94). The study also found out that groundwater recharge is immense importance to wetland

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farming in the region. It also confirmed that reduced recharge resulting from lower levels of groundwater due to the damming of the Dep river system to generate electricity has the potential of generating high welfare losses for farmers who rely on the floodplains for dry season farming.

Keywords: Floodplains; groundwater; Nigeria; fadama; valuation.

1. INTRODUCTION

The *Farin Ruwa* wetlands in central Nigeria are part of a system of water resources, both of which are surface and underground, drained by the Dep river system whose sources are mostly the north Central Plateau, and have a dendritic pattern outlook because the streams and rivulets join the main rivers at oblique angles [1]. The River Benue which constitutes the major drain for the river system originates from the Cameroon highlands and flows through Adamawa, Taraba and Benue states to form the southern border limits of Nasarawa State in central Nigeria (Fig. 1).

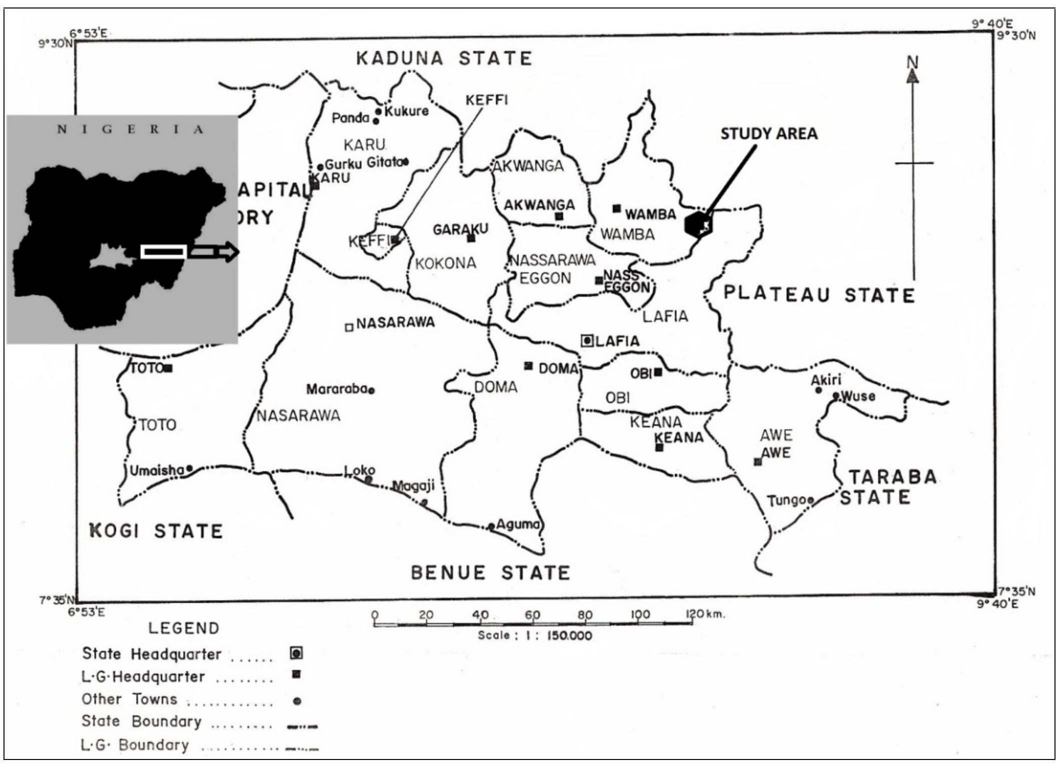

Fig. 1. Map of Nigeria showing the study area

The Dep river system is perennial and flows throughout the year but with much reduced volume of water in the dry season due to high evaporation, lack of replenishment from atmospheric precipitation and due to the upstream activity of the Lagbo Dam in the Cameroon. River Dep is fed enroute by tributaries such as Akwenyi, Gwayak, Arikia and Farin Ruwa rivers.

Surface water in this region is found in river channels, rivulets, stream, ponds and dams. The occurrence of water in the surface is perennial. The amount of water available for domestic and economic use is affected by climate and the geology of the area. Rainfall is moderately heavy ranging from 1100 – 2000 mm in the north and southern parts [2]. The wet season is characterized by flooding of ponds, rivers and streams. The volume of water on the surfaces however begins to depreciate with the stoppage of rains. Surface water becomes limited in the dry season and can only be found in the perennial streams, ponds and river systems such as Dep.

Critical to water supply for the people of the area is the water embedded in underground sources. However, it occurrence which is overlain by basement complex rock [3,4] which explains why most water schemes in the region are by river abstraction [1].

Already a state authority in the region, Nasarawa State, has planned a hydro-electric dam upstream of *Farin Ruwa* wetlands which has the potential of directly disrupting the natural flow of the *Farin Ruwa* River and by extension the Dep river system. The *Farin Ruwa* Dam project has been envisaged to greatly expand the *Farin Ruwa* Falls and the environs as well as increase its commercial exploitation in such areas as agriculture and fishing in addition to tourism and sports [5]. When completed, the project is expected to boost the economic and financial situation in the state, and generate a total capacity of 20 mega watts of electricity and create about 4000 jobs. The intention, under existing national electricity laws, is to sell part of the electricity to other neighbouring states as the entire Nasarawa State may require only 10 to 12 mega watts. In 2007, the project was expected to cost the state 36 million US dollars or about 6 billion Naira [6].

It is feared that this policy decision could have significant and irreversible consequences for the availability of an important environmental resource and the economic value of the wetlands in terms of floodplain agriculture and fishing in the region as demonstrated by studies on groundwater recharge on Hadeija-Nguru wetlands in northern Nigeria [7,8,9,10,11], for wetland degradation in Uganda [12] and for water diversion from and to Sultan marshes of Turkey [13].

These concerns have not been adequately captured by the environmental impact assessment (EIA) on the project, nor is it reflected in the state authority's development plan [14] for the region, in spite of the fact that tentative studies tend to show that these wetlands have played the critical environmental function of recharging the groundwater resources of the area [15,3,1]. Adopting the [8] methodology, this paper sets out to estimate the opportunity costs of damming the *Farin Ruwa* River to generate hydro-electricity via the valuation of groundwater recharge functions of the associated wetlands. The objective is to apply the production function approach in analyzing groundwater use in dry season farming or *fadama* (irrigated agriculture).

Following in the steps of [8], this study uses data from a survey on floodplain agricultural production to estimate the economic value of farm output per hectare of *fadama* land. Through water input, it then undertakes the valuation of the recharge function as an environmental input in *fadama* agricultural production which is assumed to rely exclusively on groundwater resources of the aquifer. In the final analysis, the study adopted the neoclassical approach to derive two welfare measures relating to the recharge function of the wetland. It then uses the estimated production function and hypothetical change in groundwater level to compute welfare change.

Agriculture is the main economic activity in the zone [16]. The zone is characterized by a tropical sub-humid climate with two distinct seasons – the wet and dry seasons. The wet season starts from the beginning of May and ends in October. The dry season is experienced between November and April. Annual rainfall in the zone ranges from 1100mm to about 2000mm. The categories of crops grown in the zone are cereals, legumes, tubers and vegetables. The cereals category includes maize, rice, sorghum and millet; the legumes category includes cowpea, groundnut, soya bean, Bambara nut, melon and beniseed; the tuber category includes yam, cassava, sweet potato and cocoyam; and the vegetables category includes okra, pepper, tomatoes, spinach and onion. Table 1 shows available crop production for the years 2002 and 2003.

The bulk of the crop production in the zone is undertaken by small scale farmers most of whose labour force, management and capital come from household. There are two main forms of cropping. In mixed cropping systems, farmers plant one major crop and two or more supplementary crops together on the same land [17]. The socio-economic reasons for mixed cropping include enhanced food production, increased farm incomes and insurance against risks and uncertainties associated with farming in the zone [18].

Table 1. Major commercial crop production for 2002 and 2003

S/ No	Crop	2002			2003		
		Production ('000MT)	Area ('000 HA)	Yield (MT/HA)	Production ('000MT)	Area ('000 HA)	Yield (MT/HA)
1.	Maize	88.04	56.40	1.56	82.40	54.93	1.50
2.	Rice (paddy)	86.00	40.00	2.15	97.49	45.13	2.16
3.	Sorghum	101.08	82.09	1.23	126.99	83.00	1.53
4.	Millet	31.00	32.00	0.97	37.12	32.00	1.16
5.	Cowpea	41.00	70.00	0.59	53.66	89.43	0.60
6.	Groundnut	97.29	78.46	1.24	69.38	62.51	1.11
7.	Yam	900.00	62.00	14.52	975.66	61.75	15.80
8.	Cassava	240.00	23.00	10.43	204.67	19.16	10.68
9.	Soybeans	3.75	2.80	1.34	2.44	1.86	1.13
10.	Bambara nut	4.50	3.90	1.15	4.37	3.80	1.15
11.	Beniseed	7.18	11.50	0.62	8.78	13.50	0.65
12.	Melon	15.04	30.00	0.05	0.46	22.65	0.55
13.	Sweet potato	55.00	10.30	5.34	75.18	10.50	7.16
14.	Acha	0.70	1.52	0.44	-	-	-
15.	Okra	31.00	1.90	1.91	4.52	2.10	2.15
16.	Tomatoes	7.30	1.70	4.29	5.38	1.15	4.68
17.	Pepper	2.21	1.75	1.26	2.21	1.75	1.26

Source: Nasarawa State Development Programme, PME Department, Lafia-Nigeria, 2004

Irrigation farming is not new to the various communities in the area as rivers and streams are among the water resources which provide a great potential for dry season agriculture. The farmers practice irrigation during the dry season to produce food crops and fresh vegetables. Here types of indigenous irrigated agriculture can be distinguished within the zone. The first is the traditional irrigation farming which takes advantage of the high water holding capacity of some soils or the high water table during the dry season to grow crops throughout or part of the dry season on residual soil moisture and the declining water table. Second, there are rainy season farmers who clear swamplands and construct ponds and small earth dams to retain, divert and drain water. This method of irrigation is mainly utilized by rice farmers. The third is the traditional irrigation system water mostly by vegetable farmers, which uses buckets and shadufs to deliver water to small plots near high water table areas or pumps to farm plots far off streams and rivers [18].

2. METHODOLOGY

2.1 Data and Methods

The data used in this study were based on field survey figures on the crops cultivated in the area during the dry season of 2008. Eleven villages, believed to be representative of the wetland area, were covered in the survey. A total of 405 farms were surveyed for crop production covering a total land area of 92.64 ha, in addition to establishing 145 shallow wells, 189 earth dams as the number of operational groundwater sources for irrigation farming in the study area. Rice (paddy), maize, soyabeans, pepper, tomatoes, okra, onions, sugarcane, beniseed and acha are the major cash crops cultivated in the study area. According to one source during at Nasarawa State Agriculture Development Authority, out of an estimated total of 47,381 farmers in the Dep-Sabon Gida Bakin Kogi agricultural area, 2,542 (5.4 per cent) were involved in fadama farming. Others such as spinach, eggplant, cowpea and hungry rice were mainly grown for domestic use often in small quantities (Table 2).

The total area using groundwater resources in the Dep-Sabon Gida Bakin Kogi floodplain under cultivations was 1,500 ha but the potential land area for irrigation was estimated to be 2,500 ha [19]. The economic and financial benefits from the output of farms survey in the study area are reported in Table 3. As in [8], outputs estimates were based on harvest figures indicated in sacks or bundles by farm owners which were later converted to weight measures. Financial prices for the output were estimated for the period November 2007 – April 2008 and from survey findings of farm gate prices collected from market survey. Economic prices for grains were computed based on World Bank data on commodity prices. For non-tradables such as vegetables, tubers and others, the standard conversion factor of approximately 1 with no additional adjustment required as a large part of the economy is serviced by autonomous market rate of N148 to US$1 with no foreign exchange premium.

Whereas the per hectare value for dry season farming in the study area is 41, 233 Naira or 278.60 US Dollar, the economic value of irrigated agriculture from the Dep-Sabon Gida Bakin Kogi influence area is 61,849,500 Naira or 417,902.3 US Dollars.

Table 2. Major commercial crops cultivated

Crop	Farmers surveyed growing crops		Area under cultivation (ha)
	Percentage	Number	
Grains			
Rice (paddy)	58.2	236	25.4
Maize	70.7	286	32.4
Average	64.5		
Vegetables			1.24
Okra	21.7	88	3.5
Tomatoes	34.9	141	3.5
Pepper (sweet)	56.3	228	4.1
Pepper (chilli)	48.2	195	3.2
Spinach	23.2	94	1.2
Onion	67.9	275	2.4
Eggplant	43.0	174	0.7
Average	42.2		
Legume			
Soya beans	12.7	51	1.1
Cowpea	8.4	34	0.8
Average	10.6		
Others			
Sugarcane	45.8	185	6.8
Beniseed	23.9	97	4.8
Hungry rice	34.6	140	1.5
Average	34.7		

SOURCE*: Author's Survey, 2008*

2.2 A Model of Production and Crop-Water

Based on production function approach, [8] provided welfare estimates to value groundwater recharge through agricultural production of wheat and vegetables in the Hadeija-Nguru wetlands in northern Nigeria. Their underlying framework was general welfare estimation theory. In this study we merely adopt the same theoretical framework and therefore reproduce their model, only to modify it to cover the production of more crops and input data from survey.

Table 3. Economic valuation of irrigated agriculture for survey villages (total area= 92.64 ha)*

Crop	Output (kg)	Financial price (per kg)	Economic price (per kg)	Financial benefits (₦)	Economic benefits (₦)
Grains					
Rice (paddy)	16,240	130.0	127.92	1,948,800	2,077,420.8
Maize	12,320	92.0	74.4	1,133,440	916,608
Vegetables					
Okra	4,500	146.0	146.0	657,000	657,000
Tomatoes	3,600	168.0	168.0	604,800	604,800
Pepper (sweet)	760	380.0	380.0	288.800	288.800
Pepper (chilli)	420	210.0	210.0	88,200	88,200
Spinach	720	172.6	172.6	124,272	124,272
Onion	740	41.6	41.6	30,784	30,784
Eggplant	170	158.7	158.7	26,979	26,979
Legume					
Soya beans	1,240	88.2	88.2	109,368	109,368
Cowpea	620	146.6	146.6	90,892	90,892
Others					
Sugarcane	2,400	489.1	489.1	1,173,840	1,173,840
Beniseed	1,840	46.3	46.3	85,192	85,192
Acha	720	98.7	98.7	71,064	71,064
Total	45,790			6,433,431	6,345,219.8
Financial benefits per ha (₦/ha)					69,445.5
Gross Economic benefits per ha (₦/ha)					68,493.3
Costs of inputs (₦/ha)					27,260.3
Net Economic Benefits per ha (₦/ha)					41,233.0

***Source**: Computed based on author's survey, 2008*
NOTE: * *Exchange rate: ₦148=$1*

2.2.1 The production function

Let us assume that farmers produce $I=1,\ldots, n$ crops, irrigated through groundwater. Let q_i be the aggregate output of the ith crop produced by the farmers. We also assume that to produce q_i the farmers will require a water input W_i, from either wells or earth dams dung on the banks of the river or stream in the Dep-Sabon Gida Bakin Kogi influence area, and $j=1,\ldots,J$ of other variable inputs such as fertilizer, seed and labour, which we can be described by the notation, $x_i,\ldots,x_J$ or by the vector, X_J. Hydrologists have established that during the irrigation farming season, the rivers and streams tend to dry up, thereby compelling *fadama* farmers to depend on aquifers in the area [18,1]. Hence the definite relationship between recharge and the amount of water in the aquifer; hence we assume that the amount of water available to the irrigation farmer for use is contingent upon the environmental resource or the level of groundwater, E_R. Thus, the aggregate production function for crop i and the associated cost of producing q_i may be expressed as:

S for all i (1)

And

$$TC_i = C_x X_J + c_W(E_R) \qquad \text{for all } i \tag{2}$$

where TC_i is the minimum costs that relates to producing q_i in one farming season, c_W is the cost of pumping water and C_x is a vector of $c_{xi} .. c_{xJ}$ strictly positive, input prices associated with the variable inputs $x_{i1} .. x_{iJ}$. To make room for the possibility of increased pumping costs from greater depths ($c_W' > 0, c_W'' > 0$), we assume c_W is an increasing function of the groundwater level, E_R. Let us also assume that the demand curve for the aggregate crop production, q_i, is inverse:

$$P_i = P_i(y_i) \qquad \text{for all } i \tag{3}$$

where P_i is the market price for q_i, and all other marketed inputs prices are assumed fixed.

If we take it that the social welfare (S_i) arising from producing q_i is measured as the area under the demand curve (3), less the cost of the inputs used in production (assuming that the demand function is compensated so that consumer welfare can be measured by the appropriate areas), we get:

$$S_i = S_i(x_{i1},..x_{iJ}, W_i(E_R), c_W(E_R)) = \int_0^{y_i} P_i(u)\,du - C_x X_J - c_{xJ} = 0$$

for all i, j (4)

We maximize (4) to get the optimal values of input x_{iJ} and water input W_i by setting the following first order conditions to zero:

$$\frac{\partial S_i}{\partial x_{iJ}} = P_i(q_i)\frac{\partial q_i}{\partial x_{iJ}} - c_{xJ} = 0 \qquad \text{for all } i, j \tag{5}$$

$$\frac{\partial S_i}{\partial W_{iJ}} = P_i(q_i)\frac{\partial q_i}{\partial W_{iJ}} - c_W(E_R) = 0 \qquad \text{for all } i, j \tag{6}$$

If we take (5) and (6) as the standard optimality conditions, then they indicate that the socially efficient level of input use occurs where the value of the marginal product of each input equals its price. If we are to take each farmer as a price-taker, we might as well assume this welfare optimum is the competitive equilibrium. Hence, equations (5) and (6) can be used to define optimal input demand functions for all other inputs as $x_{iJ}^* = x_{iJ}^*(c_{xJ}, c_W(E_R), E_R)$ and for water as $W_i^* = W_i^*(c_{xJ}, c_W(E_R), E_R)$. In turn, the optimal production and welfare functions are defined as $q_i^* = q_i^*(x_i^*, ..., x_j^*, W_j^*(E_R))$ and $S_i^* = S_i^*(x_{iJ}^*, ..., x_{iJ}^*, W_J^*(E_R), c_W(E_R))$, where asterisks indicate optimally chosen quantities.

But since from the above relationships we are interested in solving explicitly for the effects on social welfare of a change in groundwater levels, E_R , due to a fall in recharge rates as a result of the diversion of water for dam construction, we assume that all other inputs are held fixed at their optimal levels; and that aside from c_W all input and output prices are unchanged. It the follows from the envelope theorem that:

$$\frac{dS_i}{dE_R} = \left(P_i(q_i^*) \frac{\partial y_i}{\partial W_i} - c_W \right) \left(\frac{\partial W_i}{\partial c_W} \frac{\partial c_W}{\partial E_R} + \frac{\partial W_i}{\partial E_R} \right) - W_i^* \left(\frac{\partial c_W}{\partial E_R} \right) \tag{7}$$

Thus, the effect of a change in groundwater levels on the value of the marginal product of water in production, less per unit cost of a change in water input represents the net welfare change. The total costs of water pumped ($W_i^*(\partial c_W / \partial E_R)$) is also affected by marginal change in pumping costs. The effect of a change in water input due to a change in groundwater levels occurs both directly ($\partial W / \partial E_R$) and indirectly through the marginal effect of a change in pumping costs on water input (($\partial W_i / \partial c_W$)(($\partial c_W / \partial E_R$)). If per unit pumping costs are extremely high, we should expect that to certain extent an increase in groundwater levels to lead to a welfare benefit, or at least to maintain the initial welfare levels, whereas a decrease in groundwater levels would lead to a welfare loss, either due to increased pumping costs and /or change in farm productivity.

Let us now make the assumption that all farmers in the study area are faced with similar production and costs structure for each crop as captured in equations (1) and (2); and that they are all price takers. Once these conditions are granted, we can derive the aggregate welfare effect of a non-marginal change in groundwater levels due to the damming the Dep River system. Assuming there are *1, …, k* irrigation farmers producing q_{i_k} output of crop *i* and using W_{i_k} water inputs. It follows that by integrating (7) over the old level, E_{R0}, to the new level, E_{R1} and aggregating across all *K* farmers yields the welfare effects of a non-marginal change in groundwater levels on the aggregate output of crop *i*:

$$\begin{aligned} \Delta S_i &= \sum_{k=1}^{K} \frac{\Delta S_{ik}}{dE_R} \\ &= \sum_{k=1}^{k} \int_{E_{R0}}^{E_{R1}} \left[\left(P_i(q_i^*) \frac{\partial q_{ik}}{\partial W_{ik}} - c_{W_k} \right) \left(\frac{\partial W_{ik}}{\partial c_{W_k}} \frac{\partial c_{W_k}}{E_R} + \frac{\partial W_{ik}}{\partial E_R} \right) - W_i^* \left(\frac{\partial c_{W_k}}{\partial E_R} \right) \right] dE_R \end{aligned} \tag{8}$$

But to determine the welfare measure in (8), we need information on the production function for each crop and how the equilibrium output and inputs change with E_R . To adopt a different approach, we could measure the aggregate welfare effects directly from changes in social welfare, S_i , as expressed in equation (4). This translates to saying:

$$\begin{aligned}\Delta S &= S(E_{R1}) - S(E_{R0}) \\ &= \int_0^{y^1} P_i(q_i^*)dy - C_x X_j^* - c_W(E_{R1})W_j^*(E_{R1}) \qquad \text{for all } i, j \qquad (9) \\ &\quad - \int_0^{y^1} P_i(q_i^*)dy - C_x X_j^* + c_W(E_{R0})W_j^*(E_{R0})\end{aligned}$$

where y_0 is the initial output level. In order to implement (9) we need to estimate production functions for each crop and compute optimal levels of inputs and outputs. To do that there is the additional need of establishing the relationship between water and crop yield under the scenario of groundwater recharge maintenance conducive for irrigated agriculture as well as the technological ability of the pumps to abstract water from wells.

2.2.2 Irrigation inputs and crop yields

[7] and [8] have identified the stage of crop development affected by reduced or availability of irrigation water; the sensitivity of the crop to fluctuations in water availability; climatic factor such as evaporation rates; soil factors including soil type and moisture; as factors influencing the extent to which crop yields will be affected by changes in water application.

Several functional forms have been used in the literature to establish the relationship between irrigation inputs and crop yields but of particular practical relevant to this study are Mitscherlich-Spillman functions, Von Liebig function, the log-linear using Cobb-Douglas production functions, polynomial functions such as quadratic or Gompertz function which allow estimation of the effect of interesting input levels and diminishing marginal returns just as a Cobb-Douglas translog would, especially when a wider range of inputs are permitted in the system [8,20,21]. [8]'s function which uses survey data that contain information on actual quantities and market prices of inputs used and yields appears more relevant in describing the production technology of farming in the study area. This might appear to be true as it reflects optimization behavior on the part of the farmers which is more than a physical relationship between the inputs; it reflects economic decisions, too.

The damming of a river has a significant impact on the technological relationship between groundwater and wells or earth dams. By damming the river it means either a variable and uncertain flow of the river water is converted into a predictable or controllable water supply stored in an artificial lake, or diverting river and stream water upstream away from its natural course to a specific location downstream to power electricity generating turbines. Whichever is the case, the net effect is often reduced level of water recharge of aquifers, and hence the tendency to employ the use tubewell and pumps to irrigate *fadama* farms. A typical tubewell consists of a length of pipe pump casing embedded in the ground below the maximum depth to the water table. For the use of tubewell to be effective this maximum depth should be such that during water abstraction, the aquifer's water level does not fall below the pipe's reach. If the rate of withdrawal from the aquifer exceeds the recharge and groundwater levels do not recover to the original base level, the use of the tubewell will be abandoned or increased costs of pumping from a greater depth may cause pumping to be curtailed until a new groundwater level is established.

In turn, a reduction in groundwater could have two effects namely, below certain level, the costs of pumping is likely to rise; and below the maximum depth of the sunken shallow wells, the farmer will stop pumping for the rest of the dry season thereby disrupting agricultural production. Our survey in the study area has shown that shallow wells are sunk to the average of 5.4 m deep below the ground. This means that the groundwater table would have to fall to a level greater than 5.4m before extraction capacity falls to zero. For the likelihood that costs of pumping to rise, we expect that the speed of the pump will be affected by a drop in groundwater levels; however water will still be available to the farmer using the existing technology. Because the pumps used by the farmers are surface mounted pumps and are likely that at depths approaching 6m these pumps will lose speed due to additional workload in lift. In order to keep input level, the farmer may have to increase pumping hours which translates to higher costs of production. But it is possible for the farmer to continue with production in the short run.

We therefore used the data on pumping hours and the specifications of the pumps used to estimate the effect of drop in 1m of water levels (5.4m to 4.4m) on the motor speed of the pump: there was about 19.7 per cent (44,875 l/h to 36,034.6 l/h) decrease due to the inefficiency of the pumps, as most of them were purchased as second-hand machines. We then in turn used this data to compute the unit pumping cost at the new groundwater level (E_{R2}), by first deriving the functional relationship between pumping costs, c_W and groundwater level E_R for $E_{R0} \leq E_R \leq E_{R1}$ as, through the linearization of the cost function between E_{R0} and E_{R1}:

$$c_W(E_R) = a + bE_R \tag{10}$$

where $a = -19.56$; $b = 5.34$.

3. RESULTS AND DISCUSSION

3.1 Estimated Production Functions for Crops

To estimate the functions for crop in the study area, we assumed that output (q) depends on land (L), labour (B), Seeds (S), fertilizer (F) and water inputs (W). The farmers in the Dep-Sabon Gida Bakin Kogi influence area grew a wide range of crops. These crops were categorized into four groups, namely grains, legume, vegetable and others. Unlike [8] who estimated the production relationships for wheat and rice, we estimated for the four categories since they were grown by quite a number of farmers in the area. We considered linear, log-linear and quadratic functional forms for the crops. We also assumed constant input elasticities and variable marginal products for the log-linear form, noting that the coefficients estimated by using this form represented output elasticities of individual variables and the sum of these elasticities indicated the nature of returns to scale.

The production function for the grain, vegetable, legume and other crops categories were estimated using the following linear, quadratic and log-linear specifications:

$$q = \alpha + \beta_1 L + \beta_2 B + \beta_3 S + \beta_4 F + \beta_5 W + \varepsilon_1 \tag{11}$$

$$q = \alpha + \beta_1 L + \beta_2 B + \beta_3 S + \beta_4 F + \beta_5 W^2 + \varepsilon_1 \tag{12}$$

$$\log(Q) = \alpha + \beta_1 \log(L) + \beta_2 B + \beta_3 \log(S) + \beta_4 \log(F) + \beta_5 \log(W) + \varepsilon_2 \qquad (13)$$

where ε_i is the random disturbance associated with the production function; *Q, L, B, F, S* and *W* represent output (kg), land (ha), labour (workers), fertilizer (kg), seed (kg) and water (litre) respectively.

Table 4 shows the results for the production function of the four categories of crops.

Table 4. Results for the production functions of the four categories of crops (using ordinary least squares procedure)

Variable	Grains			Vegetables		
	Linear	***Log-linear***	***Quadratic***	***Linear***	***Log-linear***	***Quadratic***
Land	2.889212*	0.219977*	2.902164*	0.225613	-0.030770	0.223967
	(7.41617)	(5.69329)	(7.50162)	(0.692126)	(-0.52850)	(0.68715)
Labour	2.321234*	0.008505*	2.301495*	-0.459031	-0.001133	-0.455818
	(4.84404)	(4.34175)	(4.83775)	(-1.28394)	(-0.40350)	(-1.27391)
Seeds	-0.008580	-0.016794	-0.009346	0.031856*	0.073425	0.031477*
	(-0.61041)	(-0.52010)	(-0.66925)	(2.85711)	(1.44028)	(2.81768)
Fertilizer	-0.003886	0.012258	-0.004127	-0.021689	-0.015081	-0.022163
	(-0.99889)	(0.31953)	(-1.06760)	(0.56251)	(-0.25960)	(-0.57466)
Water	0.000134	0.025602*	2.635610	-4.54E-06	-0.005101	0.889311
	(2.93264)	(1.10074)	(3.76175)	(-0.04127)	(-0.14338)	(0.17428)
Constant	117.7035*	4.202990*	127.7559*	134.7951*	4.476457*	134.3597*
	(5.68774)	(9.38483)	(6.55206)	(8.01773)	(7.73524)	(8.27764)
Adjusted R^2	0.420619	0.342895	0.531141	0.149128	0.593157	0.141997
F-Statistic	23.75884	14.40415	25.17051	2.155042	0.522729	2.160932
Breusch-Pagan χ^2	2.10E+56 (d.f.5)	1.5E+92 (d.f.5)	1.26E+59 (d.f.5)	6.98E+53 (d.f.5)	2.63E+57 (d.f.5)	2.63E+57 (d.f.5)
Observations	405	403	403	405	405	405
Variable	**Legumes**			**Others**		
	Linear	***Log-linear***	***Quadratic***	***Linear***	***Log-linear***	***Quadratic***
Land	-0.149984	-0.062109	-0.148599	0.068694	0.045575	0.064743
	(-0.92082)	(-1.28270)	(-0.91157)	(0.434435)	(0.93298)	(0.40931)
Labour	-0.187503	-0.045444	-0.187270	0.122947	-0.014458	0.118986
	(-0.91954)	(-1.04293)	(-0.91707)	(0.66600)	(-0.32242)	(0.64425)
Seeds	-0.003875	-0.024216	-0.003884	0.001176	0.003481	0.000995
	(-0.57507)	(-0.59276)	(-0.57610)	(0.23073)	(0.08086)	(0.19541)
Fertilizer	-0.000819	-0.01078	-0.000826	0.002215	0.017669	0.002260
	(-0.41612)	(-0.21980)	(-0.41957)	(1.22320)	(0.61417)	(1.24609)
Water	2.66E-05	0.015322	0.353212	3.86E-05	0.039378	0.893121
	(0.85795)	(0.48961)	(0.49059)	(1.210995)	(1.29249)	(0.3635)
Constant	115.7234*	4.799184*	117.9175*	50.66463*	3.170352*	53.00124*
	(11.77411)	(7.945174)	(12.64278)	(7.40184)	(6.64896)	(8.38970)
Adjusted R^2	0.483139	0.691231	-0.006088	0.022501	0.502323	0.038648
F-Statistic	0.614383	0.741702	0.514720	0.820381	0.600135	0.691732
Breusch-Pagan χ^2	2.00E+57 (d.f.5)	2.63E+55 (d.f.5)	5.7E+54 (d.f.5)	4.37E+59 (d.f.5)	8.70E+55 (d.f.5)	3.55E+54 (d.f.5)
Observations	402	402	402	401	401	401

t statistic in parenthesis; * 5% significance level.

The R^2 reported for all the categories of crops ranged from 0.023 to 0.63. These are generally low values, suggesting poor fit. The Breusch-Pagan test on the four categories of crops was not significant for all the models, given the critical value χ^2 =11.07 with *d.f.* =5 at 5% level of significance; indicating we should reject the homoscedasticity assumption. A large number of coefficients on the variables had wrong signs in addition to not being statistically significant. To correct for all these we reran the equations using weighted least squares procedure with the variable, W_i, serving as weight. The results of this experiment are reported in Table 5.

Table 5. Results for the production functions of the four categories of crops after correcting for heteroscedasticity (using weighted least squares procedure)

Variable	Grains			Vegetables		
	Linear	***Log-linear***	***Quadratic***	***Linear***	***Log-linear***	***Quadratic***
Land	-4.89130*	0.542347*	4.920362*	7.703124*	0.38066*	7.691652*
	(-43.5680)	(24.69802)	(43.96626)	(7.70846)	(7.7085)	(17.8216)
Labour	3.707154*	10.79110*	3.875866*	0.501889	-0.02571	0.050793*
	(7.8580)	(0.337393)	(8.299607)	(-0.79520)	(-0.7952)	(1.43122)
Seeds	-0.06261*	0.139987*	0.064830*	0.114615*	0.24193*	0.114871*
	(-5.76952)	(4.08697)	(5.974074)	(4.653431)	(4.6534)	(9.92133)
Fertilizer	-0.02650*	0.214332*	-0.026748*	-0.870361*	0.32438*	-0.87009*
	(-32.0213)	(5.88807)	(-32.4956)	(5.87216)	(5.8722)	(-31.2002)
Water			4.329809*			3.732508*
			(4.776971)			(6.74369)
Constant	331.2592*	-80.21561*	332.5723*	167.8976*	-0.92077	167.9866*
	(29.1851)	(-0.21958)	(29.1986)	(8.47843)	(-0.5567)	(8.47802)
Adjusted R^2	0.993147	0.755463	0.993079	0.995763	0.566795	0.995768
F-Statistic	11652.59	311.4814	11537.12	23736.20	132.8191	18967.80
Observations	403	403	403	404	405	404
Variable		**Legumes**			**Others**	
	Linear	***Log-linear***	***Quadratic***	***Linear***	***Log-linear***	***Quadratic***
Land	0.546391*	0.403431*	0.545297*	-2.405733*	0.557156*	1.85631*
	(4.05833)	(9.32862)	(4.04629)	(-16.8251)	(14.7005)	(-10.45)
Labour	1.471370*	-0.010234	1.471685*	4.953545*	-0.029557	5.79588*
	(19.5594)	(-0.26207)	(19.5462)	(11.7504)	(-0.79863)	(11.414)
Seeds	0.014436*	0.235465*	0.014433*	-0.031469*	0.261086*	-0.00499
	(5.81541)	(5.26734)	(5.80901)	(-2.94196)	(5.60754)	(0.3963)
Fertilizer	-0.01107*	0.361623*	-0.011086*	-0.012334*	0.128155*	0.01029*
	(-6.1767)	(7.20470)	(-6.178627)	(-20.6998)	(3.85123)	(13.004)
Water			2.179809*			3.95530*
			(8.56270)			(4.2512)
Constant	57.62006*	-9.085484*	57.66826	50.66463*	-6.62133*	15.1450
	(9.31320)	(-4.68439)	(9.31207)	(7.40184)	(-4.08023)	(0.9233)
Adjusted R^2	0.992472	0.564210	0.992459	0.985511	0.580921	0.978834
F-Statistic	13217.54	130.7922	10555.90	6802.77	139.6183	3700.575
Observations	402	402	402	401	401	401

*t statistic in parenthesis; * 5% significance level.*

For the grains category, the three models performed well in terms of R^2 and *F* statistics, but the linear and quadratic models outperformed the log-linear specification. The coefficients on the variables *L, B, S, F, W* and the constant term were statistically significant. In terms of the signs attached to the coefficients, the quadratic model outperformed the other two with only the variable *F* having the wrong sign. Similar observation and conclusion can be drawn for the vegetables and legumes categories of crops.

The linear log-linear models of the last category of crops have R^2 of 0.986 and 0.581, and F statistic of 6802.8 and 139.6, respectively. Both the values suggest somewhat a good fit. Most the coefficients on the variables are statistically significant. However, the large, negatively signed coefficients of these variables and the fact that the variable W_i was statistically dropped due to model transformation suggest that either of the two is not considered as candidate for use in valuing the recharge function. On the other hand, the quadratic model has high R^2 (0.979) and F statistic (3700.58), and with all the coefficients on the variables being statistically significant and having the correct signs except S.

3.2 Recharge Function Values

Studies have shown that damming upstream water either for large scale irrigation purpose or electricity generation will often have the effect of impacting on the producer welfare within the wetlands through changes in flood extent, and hence groundwater recharge [13,8,9,10]. Similar to [8], we hypothesized a drop in groundwater level from 5m to 6m due to reduced recharge in the current period and calculated the potential change in welfare associated with the reduction in recharge. This has the effect of forcing farmers to adjust their decisions on production during the farming season, especially after decisions on other inputs had already been made as the impact of the reduced recharge will not be felt until after the dry season agriculture has begun.

We used the welfare change measure for non-marginal changes in the naturally recharged groundwater, R, in (8) with the results of the production function estimates to compute welfare changes for each farmer. To do that, we took it that farmers in the study area were price-takers and hence faced the $P_i(Y_i) = P_i$ demand function. We have seen in (8) that (a) the effect of R on welfare was channeled through a change in water input as a result of increased costs, $(\partial W_i / \partial c_W)$; (b) a change in water availability, $(\partial W_i / \partial R)$ which would decline only when a change in recharge were to lead to fall in groundwater level to the average depth of about 10.5m (going by the results of the shallow wells conducted during the survey). As this may happen within a single farming season, we disregarded the second effect and concentrated on the first in our subsequent analysis of welfare change.

In order to calculate the effect of changing pumping costs on water input and utilize the estimates of the production function analyzed previously, we first estimated the marginal change in water demand due to a marginal change in the cost of pumping, $(\partial W_i / \partial c_W)$. To do that, we held all other inputs fixed and allowed only water input to vary; then together with the estimates of the quadratic production function and the optimality conditions in (5) and (6) we solved for W_i :

$$P_i\left(\alpha + \beta_L L + \beta_B B + \beta_S S + \beta_F F + \beta_W W^2\right) \times 2W = c_W \tag{14}$$

$$W_i^{**} = \left(\frac{\psi * -P_i^{**} - \beta_W^{**}}{3}\right) + \left(\frac{c_W^{**}}{3}\right) \tag{15}$$

where $W_i^{**} = \ln W_i^{*}$; $\psi^{*} = \ln(1/2)P_i^{**} = \ln P_i(\alpha + \beta_L L + \beta_B B + \beta_S S + \beta_F F$; $\beta_W^{**} = \ln \beta_W$; $c_W^{**} = \ln c_W$; and *L, B, S* and *F* were all the other inputs in the specified production function for crop *i* with estimated parameters β_L, β_B, β_S, β_F and β_W. It should noted that for the vegetables production function the variable *F* was not included; for the legumes function, the constant term and *F* were not included; and other crops function, *S* and the constant terms were not included. Because either they carried the wrong signs or were statistical insignificant, we did not take them into consideration for the estimation of welfare change. Solving for $(\partial W_i / \partial c_W)$, we obtained:

$$\frac{\partial W_i^{**}}{\partial c_W^{**}} = \frac{1}{c_W} \tag{16}$$

We used this to calculate for each farmer, taking into account the estimated values for the relevant parameters and constant terms and the market price of the crop. We then calculated welfare change due to hypothesized drop in groundwater level to 6m for each farmer using the measures in (8) and (9). After that, we used the production functions in Table 5 to calculate the corresponding change in productivity due to a fall in recharge levels, as well as the optimal levels of water input from (14) and output levels form the production function. Calculated from both welfare measures in (8) and (9) we show in Tables 6 and 7 the average and total change in welfare for a drop in groundwater levels from 5m to 6m depth.

Expectedly, there was just a slight difference between the results using measures (8) and (9). That aside, it appeared that that small changes in groundwater loss due to the damming of the Dep river system would have very high associated welfare change on grains than vegetables. It is interesting to observe that although grains require less water to grow, vegetables seem to be more susceptible to water input variation than the grains. Associated welfare change is somewhat high for legumes and other crops category; however, the effect on the latter appears to be higher relative to the former.

Table 6. Welfare change for sample using eq. (8)

Crop category	Total welfare change (Naira)	Average welfare per hectare	Total land (ha)	Average land holding (ha)
Grains	8,128,487.12	140,631.27	57.8	0.221
Vegetables	8,830,691.98	445,095.36	19.84	0.134
Legumes	1,439,058.56	757,399.24	1.9	0.046
Other	2,872,113.22	219,245.28	13.1	0.097
Total			92.64	0.498

Table 7. Welfare change for sample using eq. (9)

Crop category	Total welfare change (Naira)	Average welfare per hectare	Total land (ha)	Average land holding (ha)
Grains	8,141,499.91	140,856.40	57.8	0.221
Vegetables	7,356,416.32	370,987.11	19.84	0.134
Legume	1,446,253.85	761,186.24	1.9	0.046
Other	2,642,344.16	201,705.66	13.1	0.097
Total				

***Source**: Computed based on author's survey, 2008*

The Dep-Sabon Gida Bakin Kogi floodplains have an arable area of 2,750 ha but only about 1,500 ha was under cultivation. We have noted from the survey that about 64.5 per cent, 42.2 per cent, 10.6 per cent and 34.7 per cent grew grains, vegetables, legumes and other crops, on the average respectively. The implication of this is that with an approximately 2, 542 farmers in the Dep-Sabon Gida Bakin Kogi floodplains involved in *fadama* agriculture, slight drops in groundwater level would likely affect the welfare of about 1,640, 1,073, 270 and 882 farmers growing grains, vegetables, legumes and other crops respectively. We therefore used the welfare change measures for the hypothesized fall in groundwater level from 5m to 6m depth from (9) for the welfare changes shown in Table 8.

We have previous shown that irrigation agriculture using water from the shallow groundwater aquifer was 41,233 Naira (US$ 278.6) per hectare for the Dep *fadama* area. The change in welfare due to a fall in recharge to the shallow wells, earth dam and other underground water bodies was about 3,503 Naira (US$ 23.7) and 6,156 Naira (US$ 41.6) for each grains and vegetables farmer, respectively. For legumes and other crop farmers, the average welfare change per farmer was 17,015 Naira (US$ 115) and 6,262 Naira (US$ 42) respectively. Interestingly, the welfare change for the average legume farmer is high. The reason for this might not be unconnected to the fact that soya bean and cowpea are high yield crops and response quite remarkably to water inputs. Aside from that, because of the relatively high economic returns on them, farmers in the *fadama* area are increasingly devoting more space and effort to their cultivation. When put together, the total potential loss associated with 1m change in naturally groundwater recharge levels was estimated to be 22,466,669.89 Naira (US$ 151,801.8) for the Dep-Sabon Gida Bakin Kogi *fadama* influence area.

Table 8. Welfare change in the Dep-Sabon Gida Bakin Kogi fadama in Naira*

Crop category	Average welfare per farmer	No of farmers in the Dep… *fadama* growing the crop	Total loss for the Dep… *fadama* farmers
Grains	3,502.85	1,640	5,744,674.00
Vegetables	6,156.00	1,073	6,605,388.00
Legume	17,014.75	270	4,593,982.50
Other	6,261.48	882	5,522,625.36
For all crops farmers			22,466,669.86

***Source**: Computed based on author's survey, 2008*
*NOTE: * Exchange rate: ₦148=$1*

Taking the NADP estimate of the total potential area that could be irrigated (2, 500 ha) within the Dep-Sabon Gida Bakin Kogi *fadama* influence area as well as the average welfare change for the area of 440,234.77 (US$ 2,974.56) into consideration, we calculated the total potential welfare loss of 1,062,832,391.06 Naira (US $ 7,181,299.94) for the whole wetlands as a result a potential drop in groundwater levels to 6m in depth due to the damming of the Dep river system. Regardless of the absence of remarkable difference in the level of welfare associated with the four categories of crops, the value of groundwater recharge is positive and quite substantial.

4. CONCLUDING REMARKS

The plan to go ahead with the construction of a hydro electric dam that will generate electricity using the Dep river system by the Nasarawa State government seems at odd with the overall policy objective of promoting agricultural production, controlling flooding and reducing poverty among rural farmers in the region under the Federal Government World Bank/GEF-assisted *Fadama* II initiative. It would appear the economic value of the true costs associated with diverting the water from the wetlands has not been noted and factored into the development plans in the region or state. Understandably, perhaps the reason for this might be the apparent lack of concern over the potential for over-exploitation of groundwater resources and the lack of knowledge on aquifer recharge and its impact on reduced flooding of *fadama* areas in the region.

Like similar studies, this one showed that groundwater recharge is of immense importance to wetland farming in the region. It also confirmed that reduced recharge resulting from lower levels of groundwater due to the damming of the Dep river system to generate electricity has the potential of generating high welfare losses for farmers who rely on the floodplains for dry season farming. The welfare losses might even be more severe for those farmers who are off the regular groundwater catchment areas.

Another possible consequence of this is that the groundwater recharge falls over time, there would the tendency for farmer to shift towards sinking of deeper shallow wells and drilling of boreholes to the depth of tens of metres which may have more serious implications for water management and wetland sustainability in the region. Available hydrological data on groundwater in the area indicates that groundwater sources are overlaid by basement complex rocks which have an unpredictable quantity [1]. With the apparent lack of knowledge on the exact relationship between the alluvial aquifers and the deeper aquifers of the Benue Formation, the true value of the shallow aquifers in *fadama* farming and value of the recharge function of wetlands in the area, the state government may have to reconsider the economic and financial benefits of the *Farin Ruwa* Hydro Electric dam vis-a-vis the long term implications of the project on the welfare of farmers and the environment.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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