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IMPACT OF IRRIGATION DEVELOPMENT ON VARIOUS INDICATORS OF AGRICULTURAL SECTOR COMPETITIVENESS

Abstract: *(Modern agriculture practices cannot be considered without proper irrigation systems and infrastructure. Besides balancing production fluctuation, Irrigation contributes to increased crop production and productivity in the agriculture sector. As well, irrigated agriculture plays a fundamental role in ensuring food security and self-sufficiency of agricultural products. In recent years, as a result of state investment and rehabilitation of irrigation infrastructure in Georgia, the area of irrigated lands has increased significantly. Besides, the Government of Georgia is implementing actions to rehabilitate and modernize existing irrigation infrastructure and bold investments are envisaged for coming years. This paper seeks to analyze the economic effects of additional irrigation investments in Georgia, namely impact on crop yiled and agriculture sector productivity. The quantitative evidence derived through the analytic technique is based on the survey of agricultural holdings – AGRIS. The analysis showed that the use of irrigation technology exerted positive and significant impact on crop yield and increased production in the agriculture sector, indicating that irrigation significantly contributes to the increasing productivity and can play an important role to reduce imports of agricultural products and increase self-sufficiency and food security of the country. These outcomes are expected to improve with the adoption of more efficient irrigation technologies. Furthermore, in conjunction with advancements in modern agro-technical practices, investments in irrigation are likely to lead to enhanced productivity growth.*

The land consolidation and more prevelance of individual and efficient irrigation systems will partially address productivity issues in agriculture sector, reduce irrigation costs and foster the development of agricultural commercial practices.

Keywords: *Agriculture; Irrigation, Crop yield; Survey of agricultural holdings, Propensity Score Matching.*

JEL classification: *C49, C54, Q10, Q16.*

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ირიგაციის გავლენა სოფლის მეურნეობის სექტორის კონკურენტუნარიანობის ინდიკატორებზე

აბსტრაქტი: *თანამედროვე სოფლის მეურნეობის პრაქტიკის უმნიშვნელოვანეს კომპონენტს სათანადო სარწყავი სისტემები და შესაბამისი ინფრასტრუქტურა წარმოადგენს. წარმოების მდგრადობის გარდა, ირიგაცია ხელს უწყობს კულტურების წარმოებისა და პროდუქტიულობის გაზრდას სოფლის მეურნეობის სექტორში. ასევე, სარწყავი სისტემების განვითარება ფუნდამენტურ როლს ასრულებს სასურსათო უსაფრთხოებისა და სასოფლო-სამეურნეო პროდუქციის თვითკმარობის უზრუნველყოფის მიმართულებით. ბოლო წლებში საქართველოში სახელმწიფო ინვესტიციებისა და სარწყავი ინფრასტრუქტურის რეაბილიტაციის შედეგად საგრძნობლად გაიზარდა სარწყავი მიწების ფართობი. გარდა ამისა, საქართველოს მთავრობა ახორციელებს არსებული სარწყავი ინფრასტრუქტურის რეაბილიტაციას და მოდერნიზაციას და ირიგაციაში ინვესტიციების განხორციელებას. ეს ნაშრომი მიზნად ისახავს გაანალიზოს საქართველოში დამატებითი სარწყავი ინვესტიციების ეკონომიკური ეფექტი, კერძოდ, გავლენა კულტურების მოსავლიანობასა და სოფლის მეურნეობის სექტორის პროდუქტიულობაზე. ანალიტიკური ტექნიკით მიღებული რაოდენობრივი მტკიცებულება ეფუძნება სასოფლო მეურნეობების გამოკვლევას. ანალიზმა აჩვენა, რომ სარწყავი ტექნოლოგიის გამოყენებამ დადებითი და მნიშვნელოვანი გავლენა მოახდინა მოსავლიანობაზე და სოფლის მეურნეობის სექტორში პროდუქტიულობის ზრდაზე, რაც მიუთითებს იმაზე, რომ ირიგაციის განვითარებაში ინვესტიციებს შეუძლია მნიშვნელოვანი როლი ითამაშოს სოფლის მეურნეობის პროდუქტების იმპორტის შემცირებისა და სასურსათო უსაფრთხოების გაუმჯობესების მიმართულებით. ამასთან, ეს შედეგები მოსალოდნელია გაუმჯობესდეს უფრო ეფექტური სარწყავი ტექნოლოგიების გამოყენების შემთხვევაში. გარდა ამისა, თანამედროვე აგროტექნიკური პრაქტიკის მიღწევებთან ერთად, სარწყავ სისტემებში ინვესტიციები სავარაუდოდ გამოიწვევს პროდუქტიულობის უფრო მაღალ ზრდას.*

მიწის კონსოლიდაცია და ინდივიდუალური და ეფექტური სარწყავი სისტემების მეტად გავრცელება ნაწილობრივ გადაჭრის პროდუქტიულობის საკითხებს სოფლის მეურნეობის სექტორში, შეამცირებს ხარჯებს და ხელს შეუწყობს სოფლის მეურნეობის კომერციული პრაქტიკის განვითარებას.

საკვანძო სიტყვები: *სოფლის მეურნეობა, ირიგაცია, კულტურების მოსავლიანობა, სასოფლო მეურნეობათა გამოკვლევა.*

JEL კლასიფიკაცია: *C49, C54, Q10, Q16.*

Introduction and review of literature

From the 1990s onward, agricultural sector has changed dramatically and the land used for agriculture has decreased by about 50%[1]. As well, the share of agriculture in GDP has fallen significantly over the past decades, from 22% of GDP in 2000 to 6.9% of GDP in 2023. Despite its reduced share in the national economy, the agricultural sector is expected to grow by about 4% per annum[2] and remains a very important sector. Regarding with to the social aspects and employment, 16.5% of the total employment is engaged in agriculture activities and the rural population represents more than 40% of the total population. However, the dependence on the agriculture sector, as the biggest employment-generating sector is likely to continue into the medium-term future, and it is one of the greatest challenges to improve its productivity, increase farmers' incomes and reduce rural poverty. Subsistence and semi-subsistence farming represents the major part of agriculture value-added, thus representing the main impediment factor for increasing competitiveness.

In line with increasing investments in irrigation and support to agriculture sector, agriculture competitiveness has significantly improved in recent years. Despite the unfavorable climate conditions and increasing vulnerability, value added of agriculture sector in real terms in 2023 increased by 21.4% compared to 2012. The improving trends in agriculture was attributed by increasing crop yields, more precisely compared to 2012 overall crop yield for wheat increased by 52.9%, for Maize by 8.3%, for potato by 23.2%, for bean by 12.5%, for barley by 37.5% and for vegatables by 57.7[3]. Regardless, the significant improvements, the productivity level in the agriculture sector significantly underperforms the productivity in all other sectors and crop yield is significantly lower compared to regional or peer countries.

In 2014, after signing the Deep and Comprehensive Free Trade Agreement (DCFTA) Georgia took an obligation to ensure agriculture and rural development in compliance with the EU policy and best practices and to harmonize the Georgian legislation with the European Legislation[4], which in turn creates greater opportunity to get benefits from investing in agricultural production by creating perspectives for exporting Georgian products to the EU market. Important

[1] World Bank, 2018, "A systemic country diagnostic"
[2] Agriculture and Rural Development Strategy of Georgia 2021 – 2027
3 Relevant time series data is not available for permanent crops.
4 Agriculture and Rural Development Strategy of Georgia 2021 – 2027

investments were made to increase the productivity of agricultural production under the framework of state support programs, namely during 2014-2021 more than 800 Mln. GEL was allocated for different agriculture development state support programs.

The agriculture sector and food processing have significant untapped potential to support inclusive economic growth, increase export capacity, and support productivity enhancement. In recent years Georgia introduced several support programs in the agricultural sector-oriented on the improvement of access to finance, providing insurance schemes, and quality improvement of food products, however, significant challenges still remain that are directly linked to the lack of technological upgrade, modern production, and entrepreneurship practices and low productivity.

The effects of climate change such as increasingly volatile weather and more extreme events – like droughts, floods, limited availability of water and etc. affect agriculture productivity and emphasize the importance of using modern agriculture practices. Especially, in the context of global warming, the role of irrigation is growing day by day and modern agriculture cannot be considered without proper irrigation systems. The development of productivity enhancement practices, especially irrigation has the potential to enable and strengthen local agriculture, supply chain infrastructure, enhance productivity, and support self-sufficiency and food security of the country.

Despite the fact that rehabilitation and modernization of irrigation systems in Georgia, is one of the declared priorities of Government of Georgia, there are no research papers that would analyze and assess the economic effects of additional irrigation investments in Georgia. Moreover, there is no evidence of other scientific or applied research that study irrigation issues in Georgia. Therefore, presented research paper will support awareness raising on benefits of irrigation system rehabilitation and modernization. Besides, research will assist relevant stakeholders to purse more evidence based policy-making practices, as results derived from quantitative analysis, present benefits of irrigation systems development in tangible way (concrete impact on agricultural output, employment and ect.) and make it easier to communicate to scientific as well to wider audience. The paper evaluates irrigation issues in micro and macro context thus will support proper policy insights.

Presented research is based on Agricultural Integrated Survey (AGRIS) data, that provides information for 143,323 agricultural holdings and for 387,963 parcels throughout regions of Georgia.

The paper evaluates the impact of irrigation on the crop yield for different annual and permanent crops based on one of the common and widely adopted program evaluation techniques – Propensity Score Matching.

The analysis showed that the use of irrigation technology exerted a positive and significant impact on crop yield and increased production in the agriculture sector, indicating that irrigation significantly contributes to increased productivity and can play an important role to reduce imports of agricultural products and increase self-sufficiency and food security of the country.

Irrigation impacts livelihoods through several channels including through increased intensification leading to increased food production, increased use of complementary inputs, production of market-oriented crops in addition to food crops and through a reduction in risks as farmers diversify their crop portfolio (Garbero and Songsermsawas, 2018).

As international experience suggests, together with increased productivity, there is another issue about increasing the use of inputs. Data analyses show that the irrigation impact on input use is positive as well (Jin et al., 2012). The input use is significantly higher in irrigated areas compared to the rain-fed areas. Smallholder farmers mainly focus on rain-fed cultivation. Low irrigation development is one of the factors that undermine the productive capacity of the agricultural sector. All input increases are additional costs. The input used, especially fertilizers and agrochemicals, are doubled in case of introducing an irrigation system. It can be caused by the fact that the same land plot is cultivated several times throughout the year and it is intuitive that several times cultivation needs more inputs, but even in this case of seasonal base input use change is highly significant. As evidence suggests, the regression of the number of cropping season on the plot characteristics suggests that establishing an irrigation system raises the number of cropping by 0.37, 0.25 and 0.34, respectively mixed, private and public irrigation system. This means that in case of the mixed irrigation system the number of cropping will increase by 0.37. The overall effect is an increase by 17%-25%. (Jin et al., 2012)

In addition to increasing the level of production, irrigation can also be used as a stabilizing factor for agricultural output. The main risk in the variability of the outcome through different years is systemic risks, which means the loss of output because of weather conditions, rainfall scarcity, and diseases. The risk can somehow be insured. It can be avoided for example, by crop protection programs, output insurance programs, or introducing functional irrigation systems. The first two options can be considered as variable expenses. But irrigation system is considered as a capital expense and relevant infrastructure and machines are needed to set up irrigation systems. Except, benefits from the investment in irrigation systems will be felt during years. Due to the fact that an irrigation system allows for stabilized higher production for farmers, they have higher income, consumption, and employment.

The impact of irrigation on crop yield at disaggregated level and broad economic benefits of adopting irrigation was not studied in Georgia. Consequently, the paper is limited to compare research findings and evaluations to other countries specific studies.

The irrigation issues and its role in agriculture competitiveness represented the subject of various researches conducted in Moldova, Nigeria, Tanzania, Ethiopia, Bangladesh, Pakistan, India and other countries. According to the Dowgert (Dowgert, 2010), irrigated crop yields are 2.3 times higher than those from rain-fed ground. In the developing world irrigated crop yields are always higher than in their rain-fed counterparts (Rosegrant and Perez 1997; Ringler et al. 2000; Hussain and Hanjra 2004; Lipton et al. 2005). Adebayo, Bolarin, Oyewale, & Kehinde (2018), based on Propensity Score Matching showed that causal effect of irrigation technology use on crop yield is between 1954.66 kg/ha and 2354.66 kg/ha in Nigeria. According to World Bank; CIAT (2016), in Moldova irrigation is considered a valuable measure to mitigate drought risk, increasing yield by 25–50% in normal years, while avoiding losses in drought years. Osewe, Liu and Njagi (2020) in their study found positive and significant effects of farmer-led irrigation on the smallholder farmers' per capita net crop income. Based on the results of Propensity Score Matching, they concluded that adopting farmer-led irrigation could increase the smallholder farmers' per capita net income. Based on evidance from india, Songqing, Winston, Jansen and Muraoka (2012), found that firstly, irrigation is positively correlated with agricultural productivity as both annual gross revenue per acre of land and annual net revenue per acre of land are lowest for rain-fed plots in almost all states, besides crop productivity, land use intensity and land prices, input use intensity is also highest of plots that have access to both private and public irrigation. The researchers showed that private irrigation, public irrigation and both private and public irrigation increase annual gross (or net) revenue per acre of land by 39%, 39% and 52%, respectively (in comparison to rain-fed plots).

The mentioned research focuses on those issues that have not been studied in Georgia, combining average impact of irrigation on crop yield for different crops and answers following research questions:

- What is the impact of irrigation development on crop yield for different annual and permanent crops?
- What are policy considerations regarding irrigation development in Georgia?

Paper is organized in following manner: Abstract; Introduction and literature review in section I; Methodology - section II; Results – section III, Conclusion – section IV.

I. Methodology

Data and context

The rehabilitation-modernization project of melioration infrastructure has been implemented since 2011. As a result, since 2012 to date, the area of irrigated land more than doubled and is expected to reach 200 000 ha in 2025.[5]

The fragmentation and average small size of land represents the important challenge of the agriculture sector that also negatively affects irrigation development. Parcels with less than 0.5 ha dominate the agricultural holdings and the share of such parcels in the case of annual crops amounts to more than 70%. The share of parcels below 1 hectare amounts to 87%.

Table 1: Structure of the cultivated land

Parcel size for annual crops	**Proportion of parcels**
$parcel \le 0.5\ ha$	74.7%
$0.5ha < parcel \le 1\ ha$	12.3%
$1\ ha < parcel \le 5\ ha$	8.5%
$5\ ha < parcel \le 10\ ha$	1.4%
$10\ ha < parcel \le 50\ ha$	2.2%
$50\ ha < parcel \le 100\ ha$	0.6%
$parcel \ge 100\ ha$	0.4%
Parcel size of permanent crops	
$parcel \le 0.5\ ha$	80.3%
$0.5\ ha < parcel \le 1\ ha$	12.8%
$1\ ha < parcel \le 5\ ha$	6%

[5] Agriculture and Rural Development Strategy of Georgia 2021 – 2027

$5\ ha < parcel \leq 10\ ha$	0.5%
$parcel\ \geq 10\ ha$	0.5%
Irrigated lands	
Regularly	27%
Partially	21%
Non water supplied	52%

Source: National Statistics Office of Georgia, Survey of Agricultural Holdings

In the case of permanent crops average size of land parcel amounts to 0.6 ha and more than 80% of land parcels are 0.5 or below 0.5 ha.

The Agriculture and Rural Development Strategy of Georgia - 2021-2027 sets several targets for increasing access to infrastructure and services; the development of irrigation and drainage systems and the development of climate change adaptation practices is one of the major strategic directions of the strategy.

According to the "Irrigation Strategy for Georgia 2017 – 2025" Rehabilitation investment is expected to increase the irrigable area to 200,000 hectares by 2025 and investments in irrigation infrastructure is expected to exceed 778 mln GEL. Most of the increase will result from the rehabilitation of existing gravity irrigation schemes, supplemented by private development of pumped surface water and groundwater. The considerable unexploited potential of groundwater will be studied and measures devised to enhance private groundwater development for irrigation, particularly in conjunction with drip irrigation technology, which is expected to expand to cover as much as 10% of irrigated area by 2025. Initially, it was expected that most of the systems purchased will be the less expensive Chinese ones. However, with time, and as experience is gained, purchases are expected to shift to higher quality systems from Turkey and Israel.[6]

In terms of irrigated land statistics, exact data on the volume of irrigated areas throughout Georgia is not available, meaning that there is no information on irrigated land plots with groundwater, from river basins or other channels of irrigation. Statistics are available only for areas irrigated by the "Georgian Amelioration" company through the amelioration infrastructure.

The AGRIS data showed that a significant part of sown land with an irrigation system is not sufficiently irrigated. More precisely, not sufficiently irrigated land amounts to 30.5 percent in the number of those parcels, which has an irrigation system. In the case of permanent crops, not sufficiently irrigated land amounts to 25 percent of the area of those parcels that has irrigation. The most widespread types of irrigation are canal and tube well irrigation. As the evidence suggests, the best results are achieved by using the mixed structures of irrigation systems, while the least productive is the canal system. The most part (around 90%) of the irrigation system in Georgia is based on the canal system. Due to water scarcity (associated mainly with seasonal factors), farmers can only receive water when there is enough water through the canal. The mentioned circumstances explain the problem related to the non-sufficient irrigation of different crops.

[6] "Irrigation Strategy for Georgia 2017 – 2025"

A lack of modern systems and equipment for irrigation systems creates bottlenecks, leading to an uneven supply of water resources. For example, farmers located at the springhead and middle part of the canal get water continuously, while those located near the tail part receive a small amount of water and are usually, not sufficient for irrigation purposes. As well, some farmers receive more amount of water than others, while they pay the same rates. It should be noted, that in recent years, the drip watering method has been rapidly developing, and new crops that are popular in Georgia, such as blueberries and hazelnuts, which were not traditionally irrigated, are now irrigated with drip irrigation systems.

As for irrigation systems, "Georgian Amelioration" company operates 131 irrigation systems, out of which 74 are engineering type systems, 49 - semi-engineering and local s ystems and 8 systems are subject to restoration. Irrigation systems are located in 6 regions (Kakheti, Lower Kartli, Mtskheta-Mtianeti, Shida Kartli, Samtskhe-Javakheti, Imereti) and in 28 municipalities throughout Georgia. The major part of area of irrigation lands with irrigation systems is comprised of gravity-fed irrigation systems, where water is primarily applied through flood irrigation methods (e.g., in rows, ditches, etc.), and mechanically irrigated lands, where water is supplied via pumping stations. Drip irrigation has been developing intensively in recent years.

The rehabilitation and modernization of irrigation systems is a key to supporting a greatly expanded horticultural crop production. Since the temperatures in Georgia will continue to rise and the estimated precipitation varies greatly, irrigation systems on the one hand can reduce the damage of climate change and on the other hand, can support higher crop yield.

Two of the main indicators that are influenced by the development of the irrigation system are: Increase in productivity per hectare per season and increase of the land-use intensity, meaning that the same land can be cultivated several times throughout the year. Therefore, the impact of irrigation greatly depends on the type of irrigation system used, farm location, water availability and the characteristics of the farm itself.

Due to the fact that most of the irrigation network was designed and constructed during the Soviet era, it doesn't correspond to existing land structures/management and irrigation requirements. Transition to a market economy, followed by the privatization process, contributed to land fragmentation into small land plots, with different water requirements by farms. The inter-village irrigation network was designed and built to irrigate collective farms and large contour plots of state farms and is not adapted (highly difficult to irrigate) for small-natural farm plots, while the complete rearrangement of the infrastructure is associated with high costs and is not feasible. In addition, due to the fact that irrigation systems were mostly built in the last century, are damaged to varying degrees and unable to function in their design parameters.

Land fragmentation negatively affects the agricultural sector as a whole and creates additional bottlenecks for irrigation development. For example, the biggest portion of agricultural land parcels owned is less than 0.5 hectares, which is associated with several challenges:

- Due to inter-land irrigation network development, sowing land area loss is quite significant.
- In order to irrigate land plots, the farmer needs to obtain the consent of various plots owners on which the irrigation canal must pass.

- Due to the fact that it is not feasible to install water meters separately for small land plots, the volume of supplied water cannot be measured for small land plots.
- There are cases when the main irrigation canal is operational, however, an irrigation network isn't developed for the land plots, and in order to irrigate specific farm, the irrigation network shall cross 10-20-30 other farmers' plots, most of whom may not cultivate the land and only one farmer will have to bear quite large financial costs for building a canal.

Besides there are number of challenges that are associated with the development of irrigation systems in Georgia. For instance, it is critically important to balance water demand and water supply for agricultural crops, as during drought periods, even though irrigation canals are operational and cleaned, there are cases when the water debit is not enough. Also, in some cases, when water debit is low, most of the water may flow in one direction into canals and some farmers do not receive an adequate amount of water. In addition, watering plots are mainly carried out in an "old-fashioned way" – Most land plots use inefficient ways for watering land plots. For example, the "Flood irrigation" approach, which is one of the widespread methods for irrigation in Georgia, leads to abnormally large amounts of water consumption and high water losses.

It should be noted that the revenues of the Amelioration Company does not cover the costs, therefore the state subsidizes the revenues of the company and irrigation capital expenditures. In addition, a number of irrigation infrastructure rehabilitation/development projects are underway within the framework of donor support. In particular, various projects are being implemented with the funding of the World Bank. Also, full rehabilitation of Zemo Samgori irrigation network is ongoing within the framework of EIB and ADB rehabilitation projects in Samgori.

AGRIS survey

The AGRIS data provides the information for 143,323 agricultural holdings and for 387,963 parcels in all regions of Georgia. The biggest share of surveyed agricultural holdings among regions comes on Kakheti (19.8%), followed by Imereti (13.9%), Samegrelo (12.4%) and Lower Kartli (10.8%). Surveyed agricultural holdings in other regions of Georgia amount 43.1%.

The different tables of AGRIS survey provide the information on farmers, crop and parcel level about various characteristics of an agricultural holding, including: sown and cultivated area, harvested area, presence of irrigation, harvested production, if the parcel was irrigated sufficiently or not, use of fertilizers and pesticides, agricultural machinery, production costs and information on agricultural credit. Average crop yield for annual crops is calculated as the ratio of harvested production and harvested area, however in the case of permanent crops to avoid bias it is more precise to define crop production per seedling of fertility age since the data provides information on the number of all seedlings and those seedlings of fertility age.

From the data of AGRIS survey the variables that were used for constructing the control group were: sown area of the crop, use of fertilizers, access to the credit, and capital expenditures. The survey contains the information if the parcel was irrigated sufficiently or not, subsequently the comparison factor represents sufficient irrigation of parcels. The irrigation infrastructure network is mainly spread in Eastern Georgia, while drainage systems are mainly present in Western

Georgia. More than 40% of irrigated land is in Kakheti. The Kakheti, Lower Kartli and Inner Kartli outperform other regions with overall agricultural productivity.

It is important to analyze existing trends regarding crop yield and the difference between irrigated and non-irrigated land, considering the existing structure of the Georgian agricultural sector. Besides the several binding factors, including the low level of mechanization and lack of relevant knowledge and skills irrigation has the potential to significantly increase the existing level of productivity.

Annual crops

The sown area in Georgia is dominated by the following annual crops: Maize, Wheat, Barley, Potato, Vegetables, beans and melons. Around 20% of irrigated land is temporarily uncultivated. The cultivated and irrigated land of annual crops are covered by the following crops: Maize (23%), Perennial grasses (22%) Wheat (19%), Barley (16%), Potato (7%), Bean (4%) and Tomato (3%). They constitute more than 90% of cultivated and irrigated land.

Permanent crops

The irrigated land of permanent crops is covered by the following crops: Apple (34.8%), White grape (18.6%), Hazelnut (18.4%), Red grape (8.1%), Peach (4.1%), Plum (3.7%),Persimmon (2.9%) and Walnut (2.9%). They constitute more than 90% of irrigated land.The paper applies the propensity score matching tool to check the irrigation effect on crop yield. The PSM method has been generally adopted in the impact evaluation literature and represents the common practice for such type evaluations.

Before applying propensity score matching, it is important to estimate the significance of the difference between sufficiently irrigated and not irrigated groups. The standardized difference can be used to compare the mean between treatment groups. The standardized difference compares the difference in average crop yields that are not affected by sample size. One of the most common thresholds to indicate the important difference is considered that standard difference should be more than 0.1, the standardized difference that is less than one indicates a negligible difference. The standardized difference in the case of barley, bean and herbs is less than one. The table below summarizes the average crop yield, standard deviation and number of observations for sufficiently irrigated and not irrigated plots of different crops.

Table 2: Descriptive Statistics of Irrigated and Not irrigated parcels by crops

	Irrigated			**Non Irrigated**			**Standardized difference greater than 0.1**
	Average yield	St. deviation	Number of observations	Average yield	St. deviation	Number of observations	
Permanent crops							
Apple	13.7	11.4	154	12.5	11.9	97	Yes
Hazelnut	2.7	2.5	109	1.7	1.4	415	Yes
Red	2.6	2.4	119	1.6	1.3	441	Yes

Grape							
White Grape	2.5	2.3	277	1.7	1.6	1408	Yes
Annual crops							
Herbs	7163.7	12030.9	1565	6493.2	11552.8	5131	No
Beans	1262.8	1248.4	369	1193.5	1472.8	1287	No
Potato	11164.5	8959.2	846	9237.6	8020.3	2974	Yes
Maize	4070.1	4377.3	474	1850.3	2062.6	2973	Yes
wheat	3054.0	1102.4	28	1808.0	830.0	322	Yes
Barley	2110.6	1078.3	39	2029.0	1134.2	356	No

Source: Developed by the author

General methodology and scope of the quantitative study

The model that estimates the impact of irrigation on crop yield uses quantitative evidence based on the survey of agricultural holdings –AGRIS. One of the most important estimates for modelling purposes represents the data of crop yields for different annual and permanent crops in irrigated and non-irrigated parcels and the distribution of irrigated land by crops. The model estimates the macroeconomic impact and channels of investments in irrigation. The figures of planned irrigation investments are based on "Irrigation Development Strategy 2025".

For the evaluation of broad economic impacts of irrigation, the the bottom-up approach was used to evaluate the quantitative impact of irrigation, as firstly based on AGRIS survey data and Propensity Score Matching technique there were calculated average treatment effect - the impact of the adoption of irrigation on crop yield, secondly, considering the distribution of irrigated land by crops, the weighted impact was estimated separately for annual and permanent crops and mentioned aggregated results was integrated into a macro assesments that in turn includes Input-Output tables.

Irrigation Impact evaluation on crop yield - Propensity Score Matching technique (PSM)

Most studies use propensity score matching (PSM) to estimate the impacts of irrigation development interventions. The literature shows that the Propensity Score Matching evaluation techniques were used in several countries to estimate the impact of irrigation on crop yield and crop income (for instance, Ogunniyi Adebayo, Omonona Bolarin, Abioye Oyewale and Olagunju Kehinde, 2018 and Maurice Osewe, Aijun Liu and Tim Njagi, 2020).

The PSM evaluates crop farmers' propensity to irrigate or not and it is commonly estimated using the Logit regression as a function of observable characteristics and then matches each crop parcel with a similar propensity score. The Propensity Score represents the probability that a farmer would adopt irrigation based on observable characteristics. The logit regression has the following form:

$$Logit(P_I) = \frac{1}{1 + e^{-(b_0 + b_1 * area + b_2 * use\ of\ fertilizers + b_3 * credit + b_4 * capital\ expenditures + b_5 * regional\ dummies})}$$

The observable characteristics that produce the probability of sufficient irrigation are the following: sown area of the crop, use of fertilizers, capital expenditures, access to the credit and regional dummies. The variable - use of the fertilizers represent the dummy variable that gets value 1 if the farm uses the fertilizer and 0 if does not. The logic is that if a farm already uses some production practice to increase crop yield, it has more willingness to adopt irrigation and support increasing crop yield more. As well more harvested area motivates incentives for adopting irrigation, due to the scale effect and higher potential benefits to generate higher revenues. Farmers that have access to the credit, in turn, have more possibility of adopting irrigation. With the same rationale, capital expenditures also support irrigation. Regional dummies were selected based on regional characteristics and availability of basic infrastructure or practice that promotes the prevalence of irrigation. Consequently, three regional dummies were selected for Kakheti, Lower Kartli and Inner Kartly, while Western Georgian regions represent the baseline for those dummies. All of the above-mentioned variables represent the significant variables for adopting irrigation in the Logit model.

The evaluations based on Propensity Score Matching in different countries together with the mentioned variables also use the rainfall information, farming experience, farmer's education and household size. The mentioned variables are not available in AGRIS survey, however taking into consideration national context, a high share of subsistence farming and significant lack of skills and capacity, based on farming experience and education, agricultural holdings in Georgia provide quite homogenous sub-groups and do not produce a significant increase of variance of Propensity Scores. The access to credit, regional dummies and farm size represent the significant factors of adopting irrigation, consequently, by including these variables, the analysis minimizes the bias in irrigation effect, since these variables are related both to assignment and to the outcome.

The next step envisages the search for the fit counterfactual(s). The obtained propensity score is usually used to create matched samples, homogenous subgroups with similar propensity scores. After constructing propensity scores for fitting counterfactuals that match parcels depending on their propensity score paper uses the stratification matching approach to calculate the average treatment effect. Matching on the stratification score leads to more accurate matches, sufficiently irrigated plots are matched to control participants who have a similar probability of adopting irrigation based on all relevant characteristics provided by AGRIS data. The entire set of propensity scores were divided into five mutually exclusive subsets. Differences in yield between sufficiently irrigated and not irrigated parcels in each interval were calculated for different crops. The average treatment effect represents the weighted average of outcome differences per interval. In general, to calculate the overall average treatment effect, stratum-specific estimates of effect are weighted by the proportion of subjects who lie within that stratum. The stratification does not consider bad matches from the control and reduces variability.

The overall model is statistically significant at a P-value equals to of 0.00. The signs of the coefficients in the table show the direction of change in the probability of sufficient irrigation given the change in the explanatory variables. The significant variables that affect the use of irrigation technology are plot size, access to credit, capital expenditures, use of fertilizers and all regional dummies. The model showed a significant and positive relationship between plot size and the probability of adopting irrigation since farmers with higher farm sizes can get higher revenues due to the increasing crop yield. Capital expenditures are positively associated with the probability of use irrigation in holding. The use of fertilizers was found to increase the probability of irrigation use. The Positive and significant relationship was found between access to credit and adoption of irrigation technology, suggesting that the farmers with credit availability have more possibility to adopt irrigation. Access to credit represents one of the major problems in Georgia for farmers. Consequently, access to credit is one way to improve farmers' access to new technology, including the adoption of irrigation and increasing farmers' ability to purchase inputs. All regional dummies in the model exerted a significant and positive impact on adopting irrigation, suggesting that farmers in Eastern Georgian regions: Kakheti, Lower Kartli and Inner Kartli are more likely to adopt irrigation.

The results provide balanced propensity scores and large overlap of propensity scores that implies a good match of treated and control cases. For testing the good match Standardized Bias (SB) test was applied that compares whether the means of covariates differ between the treated and the matched control groups. The results show that difference of propensity scores between the treated and control groups is statistically insignificant in each stratum (SB test in each stratum is less than 0.1, I stratum 0.06, II stratum 0.09, III stratum 0.07, IV stratum =0.07, V stratum 0.08), as well SB test shows that there are statistically insignificant differences in each observational variable between treated and control groups.

Table 3: Determinants of the use of irrigation

Variable	**Description**	**Coefficient (standard error)**	**Probability**
regional dummy - Lower Kartli***	1 if agricultural holding is located in Lower Kartli, 0 otherwise	0.883 (0.042)	0.0000
regional dummy -Inner Kartli ***	1 if agricultural holding is located in Inner Kartli, 0 otherwise	1.492 (0.040)	0.0000
regional dummy – Kakheti ***	1 if agricultural holding is located in Kakheti, 0 otherwise	0.134 (0.038)	0.0002
Area **	Area of plot in ha	0.010 (0.004)	0.0118
use of fertilizers ***	1 if fertilizer was used on the plot, 0 otherwise	0.104 (0.030)	0.0006
CREDIT ***	1 if holding has access to credit, 0 otherwise	0.426 (0.097)	0.0000
capital expenditures *	Amount of capital expenditures (thousand GEL)	0.009 (0.000)	0.1076

***Significant at 1% level, **Significant at 5% level, *Significant at 10%

Source: Developed by the author

Results

The analysis based on Propensity Score Matching showed that the use of irrigation technology exerted a positive and significant impact on crop yield. The results of the analysis for different cops indicates that irrigation significantly contributes to the increased productivity and can play an important role to increase agriculture production and reduce import.

The table below shows the Average Treatment Effect of adopting irrigation on crop yield for different crops. It is important to express these figures in percentage terms to evaluate how much percentage increase of crop yield is associated with sufficient irrigation for different crops. As mentioned above, crop yield for annual and permanent crops was calculated differently to avoid the bias in the case of permanent crops caused by different figures of the area occupied by permanent seedlings and area occupied by seedlings with fertility age. It is worth mentioning that figures of weighted crop yield estimated based on the mentioned analysis are consistent with the data provided by National Statistic Office.

The Average Treatment effect shows that if any crop farmers in the population used the irrigation technology the crop yield of the farmers will be increased by mentioned number in the table. As table shows, irrigation has the highest impact on crop yield in the cases of maize and the lowest impact in the case of apples. It can be explained by the fact that apple has roots deep in the ground and consequently, even without irrigation can get groundwater, while maize is not sowed at enough depth.

The difference in crop yield between irrigated and not irrigated parcels is significant in the case of Hazelnut, Red grape, White grape, Herbs, Potato, Maize and Wheat. Considering the distribution of irrigated land, the weighted average treatment effect in the case of annual crops amounts to 48% and 28% in the case of permanent crops. The weighted average of expected yield increase for permanent crops is lower due to the small effect of irrigation on the yield of apples that occupies 35% of irrigated land of permanent crops.

The highest difference in crop yields of annual crops between irrigated and not irrigated parcels was observed in the case of maize that represents 23% of irrigated land and 39% of the whole sown area of annual crops. These results are consistent with the different estimates that irrigation can double the yield of maize compared to rain fed maize. The highest difference in crop yields of permanent crops between irrigated and not irrigated parcels was observed in the case of red grape amounting to 67.7%.

Table 4: Average impact estimates of PSM: Stratification Matching

	ATE	ATE in % terms	T statistics
Permanent crops[7]			
Agregate effect	0.5***	31.5%	5.6
Apple	0.3	2.3%	0.8
Hazelnut	1.1***	66.1%	5.5
Red Grape	1.1***	67.7%	6.1

[7] crop production per seedling of fertility age

White Grape	0.4***	20.3%	7.0
Annual crops			
Agregate effect	1125.6***	38.2%	6.2
Barley	325.9	16.1%	0.4
Herbs	613.8**	9.5%	1.99
Beans	232.1	19.4%	0.82
Potato	2356.2***	25.5%	6.0
Maize	2166.5***	116.9%	17.9
wheat	1179.4***	65.2%	7.4

***Significant at 1% level, **Significant at 5% level, *Significant at 10%

Source: Developed by the author

These numbers demonstrate that irrigated agriculture will continue to play an important role as a significant contributor to the increase of food supply and self-sufficiency of agricultural products. In order to reduce the negative nature of the extreme weather events, like droughts and heatwaves, which causes sharp deficit of irrigation water, first of all, the advantage should be given to irrigation of the permanent crops, on the one hand to avoid the neccessity of new caltivation and relevant costs and on the other hand to avoid losses due to the reduction in harvest.

As international experience shows, the impact of irrigation is different across different irrigation systems, farm locations, water availability, and the characteristics of the farm itself, however, different researches proved that the productivity of the households with all three irrigation systems was higher than in rain-fed areas. For example, evidence from India (Jin et al., 2012) suggests that productivity increase for the mixed irrigation systems is 46%, while the revenue is increased by 39% for private and public irrigation systems and 52% for both mixed structures.

Several studies that used Propensity Score Matching found positive and significant effects of farmer-led irrigation on the smallholder farmers' per capita net crop income and crop yield. According to Propensity Score Matching evaluations (Osewe et al., 2020) found that in Tanzania the Average Treatment Effect on net per capita crop income in percentage terms amounts to 41%.

Conclusions

Research Findings

This study focused mainly on providing an answer to the question of how much impact the use of irrigation has on crop yield and are wide economic benefits of additional irrigation investments in Georgia. The paper showed that irrigation investments generate significant economic benefits and greatly support agricultural competitiveness. The results are based on the effects of irrigation on crop yield in the existing environment in agriculture, while in the case of more efficient irrigation technologies and in line with the development of modern agro-technical activities, irrigation investments will produce higher economic benefits. The irrigation technology use is not a substitute for other productivity-enhancing factors rather a complementary factor. The irrigation effects provided in the paper can increase in the future since state support programs promote the adoption of drip irrigation facilities that provide 90% efficiency compared to the 60% efficiency of surface irrigation thus recently representing the most widespread irrigation facility in Georgia. Changes in the distribution of irrigated land in favor of permanent crops excluding apples will also support higher economic effects.

The study has substantiated that irrigation in the study area significantly improves the crop yield, supports agriculture competitiveness and reduces import dependency. The role of irrigation is steadily increasing due to the climate change vulnerability.

In order to reduce the negative impact of extreme weather events, like droughts and heatwaves, which causes sharp deficit of irrigation water, first of all, the advantage should be given to irrigation of the permanent crops, as in the case of declining and/or abstaining plants, in addition to the need to be expelled and newly cultivated, farmers can not afford to harvest which leads to the additional losses.

The limitations of the research

The research focuses on important issues for evidence based policy implementation that have not studied in Georgian reality yet and consequently, research has several limitations. The limited sample size and data availability for niche high value added crops with high export potential that occupies relatively small share of cultivated land in Georgia represents the one of the shortcomings of the research. In overall paper provides estimations for the crops that accounts majority of cultivated land.

The analysis discussed in the paper fully relies on actual figures and variables based on the existing widespread irrigation facilities in Georgia, however different types of irrigation can yield different impact on crop yield considering different efficiency levels of different types of irrigation facilities. Subsequently, positive economic effects of irrigation can increase over time, in accordance with more prevalence of more efficient irrigation facilities, like drip irrigation. For instance, drip irrigation brings multiple benefits to adaptation and productivity: increases soil fertility; reduces heat stress and decreases post-harvest loss. In the case of increasing data coverage and providing more detailed data by types of irrigation, there is room for further research to evaluate the economic effects of different irrigation schemes. Besides, useful research can be done regarding the role of irrigation in the context of climate change adaptation in agriculture, since those issues are not explored sufficiently in Georgia.

Policy implications

Setting up an irrigation system is associated with high capital costs, leading farmers to weigh up options whether or not to install irrigation systems. On most occasions, their decision depends on the characteristics of the land, the weather in the area, and the capital costs of the irrigation system. Government can support eliminating high capital costs for farmers by subsidizing capital expenditures of setting up irrigation systems and promote the development of individual, modern irrigation schemes. As discussed below, existing irrigation systems is associated with high maintenance costs, as well as efficiency shortcomings. Reduction of maintenance costs is linked to the consolidation of lands, therefore policies that support land market development and consolidation of fragmented plots represent the important factor for increasing efficiency of irrigation systems and overall agricultural competitiveness. To this end, Government may consider shifting its irrigation rehabilitation and modernization policies towards more market based approach, meaning that irrigation network construction should be based on commercial principles. For example, instead of rehabilitating old and amortized irrigation infrastructure, it might be more feasible to arrange boring wells or small water reservoirs for commercially viable agricultural holdings.

It should be underlined that, several state support programs, under the Rural Development Agency of the Ministry of Agriculture and Environment protection of Georgia, already support development of modern irrigation systems in Georgia. For example, according to the recent changes in state support program "Plant the Future", in order to benefit from the program it is necessary to have an irrigation canal or a boring well, and in case of absence of irrigation network, it is possible to finance the arrangement of a boring well with program component. As prerequisite for the operation of any irrigation systems is water debit. Besides, it is important to promote/introduce other types of modern irrigation systems, including drip irrigation systems. Instalment and operation of modern irrigation systems is associated with significant costs and requires proper maintenance. There is still a lack of knowledge and experience in Georgia in terms of maintenance of modern irrigation systems. For instance, it is quite common to damage irrigation systems during mowing the lawn or harvesting activities. Renovating such irrigation systems can be associated with significant additional costs.

In order to increase efficacy of agricultural state support programs, on one hand it is important to increase access to finance for farmers and on the other hand support in adaptation of modern technologies. Combining grant component along with and a technical assistance (knowledge/technical expertise growth) component should also be considered within state support programs design. As of now, the importance of the technical assistance component is not properly acknowledged within the state support programs from farmers as well from implementing agency's' side.

Besides, other challenges associated with irrigation and discussed in Data and Context section needs to be tackled in order to ensure efficient, uninterrupted provision of melioration services and minimize the dependence of agricultural production on climate conditions.

The land consolidation and more prevelance of individual and efficient irrigation systems will partially address productivity issues in agriculture sector, reduce irrigation costs and foster the development of agricultural commercial practices.

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