Article

A production function approach to estimate agricultural yield benefits of sacred groves: Evidence from sacred groves of Kachchh, Gujarat, India

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Abstract
The study is pivotal because of the uniqueness of the study-site. This is because on one hand the saline and marshy deserts of Kachchh makes the groundwater levels low and a region less conducive for agriculture but, the presence of perennial water source inside the groves are likely to provide moisture to nearby fields through underground aquifers that could be facilitating agriculture. The estimate of soil acidity from WLS model is 0.019% for cereals compared to 0.053% for cereals in 2SWLS respectively. A comparison of the soil acidity estimate shows a substantial downward bias (178.94%) for cereal yields in estimation using WLS as compared to 2SWLS. According to theory, I expect a negative sign on the coefficient of soil acidity - with a unit increase in soil acidity, agricultural yields reduce. The endogeneity test suggests that environmental quality is an endogenous variable with a F-statistic value of 4.163 with 1 restriction and 175 degrees of freedom with a p-value of 0.04. In this study, I reject the null hypothesis of exogeneity of environmental quality (soil acidity) at 5% significance level. I have got a U-shaped relationship between distance and soil acidity. An increase in distance from 6 to 7 kilometers, increases acidity by 100*{[-0.59+2*.047*(7)]}=0.068*100=6.8%. Additionally, it has been estimated that as we go further from sacred grove, soil acidity increases after six kilometers. However, before six kilometers, say, going from two to three kilometers, away from sacred grove, soil acidity is declining (giving it a U-shaped). This is because of high-level of acidity due to lignite mining and other industrial pollution. This study would also add to the existing database of the studies related to the valuation of ecosystem goods and services that highlight economic consequences of decline in ecosystem services initiated under the TEEB-India initiative.

Keywords production function; ecosystem services; sacred groves; conservation.

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1 Introduction

The sacred groves provide supporting and regulating ecosystem services in addition to the provisioning and cultural services. Supporting services are those that are required for all other ecosystem services to be produced. They differ from provisioning, regulating, and cultural services in that their effects on people are typically indirect and take a long time to manifest, whereas changes in the other categories have more direct and immediate effects. It's critical to comprehend the role of societal changes in restoring cultural legacy, which is one of the holy groves' most essential ecosystem services. This further strengthens the conservation and restoration of groves. It may also be pointed out that cultural heritage and forest vegetation are associated to each other in determining the ecosystem health of community-based biodiversity conservation institutions like sacred groves. Generally sacred groves emanate ecological rewards to the ecosystem based on the geographical location, topography and climatic condition. Sacred groves provide services like floods regulation, water purification, maintaining an optimum temperature, availability of a botanical garden and arboreta for academic purpose and nature enthusiasts, a model of wild relatives of cultivated plants, storehouse of wild medicinal and edible plants, it also provides shelter for birds and insects, areas of regional environmental studies, home of microbes and fungi, etc. Ecological processes taking place in the sacred groves are responsible for recycling nutrients, soil fertility and providing the supporting services to the human societies. The sacred groves are self-sustaining ecosystems that protect indigenous, endangered, and threatened species, as well as medicinal plants and a diverse range of cultivars. Water and soil conservation is the well-documented ecological benefit given by sacred groves in the Indian desert, which helps prevent flash floods and ensures water supply throughout the dry season (Joshi et al., 2015; Agarwal, 2016; De, 2017; Singh et al., 2020; Parthasarathy and Babu, 2019).

Soil moisture is one of the important parameters in the hydrological cycle to drive weather conditions, plant growth, groundwater storage, etc.; thus, it has a role in global climate. Soil moisture consists of only 0.05% of the total water in the global hydrological cycle and 0.001% of the total available freshwater, but it has been declared as one of the Essential Climate Variables due to its important role in the hydrological cycle. Soil moisture is the soil parameter that captures the water cycling potential of the soil in the sacred grove premises (Robock et al., 2005; Lin et al., 2018; Maikhuri and Rao, 2012).

Pritchard et al., 2000 has described the ecosystem service valuation as finding the integrative metric based on three rationales: (1) to describe the linkage of natural systems with human welfare which are included in the decision-making procedure, (2) to describe the associative significance of various types of ecosystems, or (3) to analyze a particular decision in particular place, e.g., cost/benefit analyses. Consequently, valuation leads to diverse constituencies ranging from free-market advocates who affirm it will improve economic efficiency, to the managers who are in search of integrative metrics to guide decision making, to environmentalists who believe that the existence of neglected natural resources will be enhanced by the acknowledgement of their value (Carpenter and Turner, 2000).

Commenting on the limitations of studies doing valuation of forest ecosystem services, Pattanaik and Burty (2003) commented that the earliest study on forest ecosystem services valuation by Costanza et al. (1997) included some forest ecosystem services, but suffered from multiple criticisms as it did not conform some of the basic tenets of valuation. Similarly, ecological models that relate individual forest qualities to specific forest ecosystem functions were rarely used by researchers who assessed values for specific forest attributes (especially for recreation activities). The links between ecosystem functioning and services were not well spelled out in some cases, such as wetlands and the atmosphere, where some proxy for the ecosystem service (e.g., saline concentrations in estuarine wetlands or atmospheric ozone concentrations in farming counties) was related to a production activity (e.g., shrimp or corn).

Using Freeman (1993), Pattanaik and Burty (2003) specified the economic principles for valuation as the product of three sets of functional relationships. In their words, public policies combined with interpersonal perceptions of the individuals duly affect forested watersheds, decline watershed flows, and, also causes monumental changes in the ecosystem services. These services further affect personal production of the activities related to the economic agents and its economic welfare. This change in welfare is thus estimated in terms of market prices of the private commodities which further give the use value of that “ecosystem service”. Fig. 1 describes the stages of ecosystem service valuation in simple diagrammatic steps linked with the production function approach to valuation.

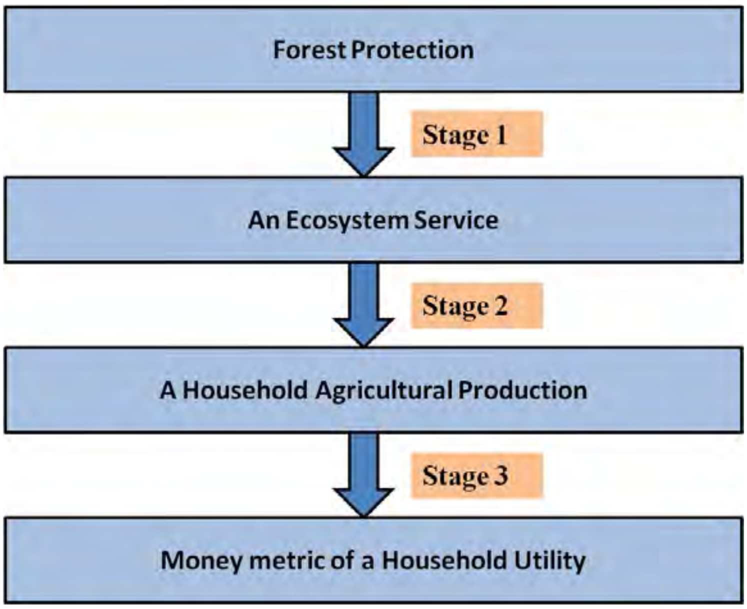

Fig. 1 Freeman (1993) three-stage framework for ecosystem servicevaluation (taken from Pattanaik and Burty, 2003).

The first stage of analysis is associated with developing an index of ecosystem service (e.g., quantity or rates of runoff, stream flow, soil quality) and the second stage includes estimation of anthropogenic utilization of ecosystem service (data on ecosystem service). Households utilize manual as well as other inputs, on the non-market ecosystem service and other fixed inputs, to produce quantities of commodities for commercial and domestic consumption. Ecosystem services therefore is considered as a consistent input in the production of final services which is give rise to the utility (household production theory) or agricultural products. The third stage of the analysis comprises of determining the economic value in relation to the commercial values of the commodities which are related to a particular ecosystem service.

2 Study Area and Methodology

Production function approach has been used to value yield benefits of forests-related environmental services. Yin and Hyde (2000) used the production function approach to show that forest-related environmental services have a causal relationship with agricultural productivity. They used longitudinal data for five prefectures in Shandong province of China observed over thirteen years, to show that agro-forestry ecosystems, where crops are gown along with trees, internalize the positive externalities contributed by forests to the land management system. Ren et al. (2019) through the review of literature and global data explained the relationship between small farm-size and environmental degradation. Smaller farm-size uses higher amount of non-fixed inputs such as fertilizers that reduces the soil organic carbon content of the farmland and increases carbon-stocks. On a similar background of agricultural productivity but in different context, Mendelsohn and Wang (2017) have used production function in selected farmlands of China to estimate the impact of climate change on soil fertility leading to the impact on production yields from the farmlands. The authors have revealed that the Green Revolution was not equally beneficial to every farmer. Farmers with more suitable climate and soil conditions got a much larger productivity gain. These additional output gains made adding more inputs more profitable. As a result, farmers in more suitable climates were able to further intensify inputs. However, even in China, farmers with poor natural endowments tend to continue to rely on low input farming. The ability of a forest to produce wood, oxygen, or specific fruits is referred to as a production function of the forest. The value this function has for a particular stakeholder (or group of stakeholders) will be determined by the stakeholder's need for that wood, or the importance the stakeholder places on CO_2 sequestration from the air. As long as no double counting occurs, the values attributed by different stakeholders (both negative and positive) can be added up to arrive at the total economic value of this particular forest. (Lette and Boo, 2002; Mendelsohn et al., 1994).

The Utah State Experiment Station and the United States Department of Agriculture conducted agronomic field and laboratory studies in tandem with output performance studies. These studies provide estimates of output responses for alfalfa, canning peas, potatoes, and sugar beets using various levels and combinations of water and fertilizers. Estimates of heterogeneity in yield response linked to crop rotation sequence and water application manner were also derived. In crop cultivation, fertilizer and water applications are critical. Particular the importance of agricultural production economics today, obtaining more precise estimates of crop response to fertilizer and water applications on a given soil should be a worthwhile study topic. Furthermore, the rate at which inputs substitute for one another in the production of a given yield must be known in order to establish a basis for identifying the lowest-cost input combinations (Nathan, 1971; Harries, 1947; Debertin, 2012).

Despite expanding interest in ecosystem service research over the past three decades, in-depth understanding of the contribution of forests and trees to food production and livelihoods remains limited (Pattanayak and Butry, 2003). Reed et al. (2017) have reviewed the evidence-based contribution of the forest and trees to agricultural production and livelihoods in the tropics, where production often occurs within complex land use mosaics that are increasingly subjected to concomitant climatic and anthropogenic pressures. Using systematic review methodology, the authors have investigated the effect of forest or tree-based ecosystem service provision on a range of outcomes such as crop yield, biomass, soil fertility, and income. The findings of the research suggest that when incorporating forests and trees within an appropriate and contextualized natural resource management strategy, there is potential to maintain, and in some cases, enhance yields comparable to solely monoculture systems. Furthermore, the review has also illustrated the potential of achieving net livelihood gains through integrating trees on farms, providing rural farmers with additional income sources, and greater resilience strategies to adapt to market or climatic shocks.

Despite this, contemporary development pathways - particularly within the tropics - often tend towards “conventional” approaches to agriculture and food security that deplete the natural resource base (Gibbs et al., 2010; Gibson et al., 2011). Forest conservation rhetoric largely refers to the benefits for the global community. Meanwhile, conservation of forests and trees at the local scale is often sold as generating other tangible benefits to farmers and rural people through the provisioning of ecosystem services (Roe et al., 2014; Steffen et al., 2015).

In my study I have used the production function of the household to estimate the contribution of the sacred groves to their production. From the primary household survey, it has been documented that the households imply some number of manual inputs such as man labor, fertilizers, manures, water etc. in their farmlands and reap the output. The existence of the selected sacred groves in the Gugaliyana reserve forest provides freshwater availability in terms of underground freshwater aquifer which helps the farmer to irrigate their farmlands and other favorable soil organic materials that are likely to improve the productivity. The study reveals that there is an increment in the outcome these farmers get out of their farmlands which otherwise would certainly have been reduced in the absence of these sacred groves despite applying the same amount of input. This exemplifies the significance of the conservation of these virgin tract forests called “sacred groves”.

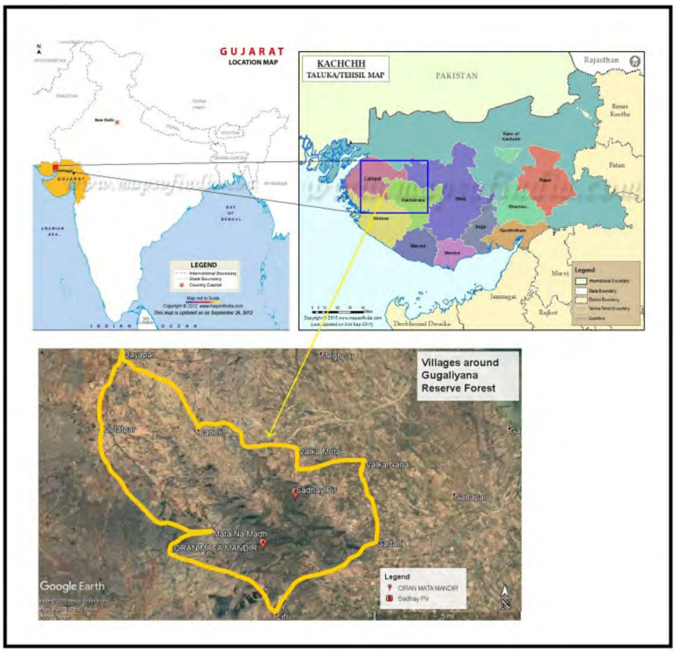

Fig. 1 Cartographic representation of the study area.

Kachchh district of India, a peninsula, is situated between Sindh and Saurashtra region, in the north-western part of Gujarat state. The temperature at Kutch-Bhuj district ranges from 45.8°C (June-2011) higher in the summer and 2.0°C (January-2011) lowest in the winter (in January Month). Maximum relative Humidity 100% and the range of seawater temperature is 16.8°C to 31.8°C. The average annual rainfall is 345 mm. In addition to its unique climatic condition, Kachchh has red soil with very little opportunity for cultivation.

The district consists of two major ecosystems i.e. Great Rann of Kachchh and Little Rann of Kachchh having an area of 12,454 km^2. It mainly covers Kachchh Desert Sanctuary in Great Rann of Kachchh (GRK) and Wild Ass Sanctuary in Little Rann of Kachchh (LRK). GRK and LRK are the most saline and marshy tracts of the forest in the world (Vijaykumar et al., 2007). Despite of an arid region, this region has a special and different plant species population status in comparison to the other deserts as it is near to the sea due to which sea water enters the soil and leads to the underground water recharge and further entertains the existence of biodiversity which otherwise is a challenge with many other arid deserts of the world. Kachchh has now become a district of critical importance from biodiversity point of view because of the presence of rare and endemic species of flora (eg., *Salvadora*, *Avicennia*, Tamarind, Banyan tree) and fauna (Desert fox, Bats, Chinkara, Spotted Deer) which are of high value at both national and international level. Survival of the world’s only inland mangrove is one such example, *Avicennia marina* the mangrove species found in the inland forest in Kachchh has proved the ecosystem worth of the district. Considering the qualities which are abundant and rampant in Kachchh, the core Advisory group of experts of United Nations Educational, Scientific and Cultural Organization (UNESCO) has declared the whole Kachchh as potential site for biosphere reserve. It is the largest biosphere reserve in the country.

By far 42 sacred groves have been reported from the district (Patel et al., 2014) in the Kachchh district. Khodiyar Mata, Oran Mata, Jhalai Mata, Panch Krishna, Mahadev is some of the deities to whom these sacred groves are dedicated. These sacred groves are associated with 150 years old trees surviving till date, which is worshipped by the local people. For my study, I have focused on two of the above sacred groves: Oran Mata and Sadhay Pir. These sacred groves are of 2 and 3 hectares respectively and located in a hilly tract of Gugariyana Reserve Forest. About 78 species of flora which constitute 75% of the tree species of the arid region of Gujarat state were recorded from these two sacred groves, comparable to other sacred groves of India despite their small size (Patel et al., 2014). The two sacred groves have been studied within the buffer zone of Gugariyana Reserve Forest. This is commonly done in many studies relating to sacred grove (Krishna and Amrithalingam, 2014; Swamy et al., 2003). The anthropogenic pressures on these sacred groves are mainly over grazing (see Fig. 1).

2.1 Theoretical model

For a firm that produces a single output q uses a single variable input x and if affected by some environmental qualities ES, then Cobb-Douglas Production Function is given as follows in equation (1)

$$q = \alpha\, x^{\beta} ES^{\gamma} \quad (1)$$

where,
q = output;
x = variable input (labor);
ES = Environmental quality;
α, β, γ are the parameters to be estimated;
Variables q, x and ES are all assumed to be positive (>0),

The two inputs interact in a multiplicative way and both are essential for production function (x=0, or ES=0, so q=0).

It is assumed that the production is well behaved in the sense that $\alpha>0$ meaning α is positive, which is necessary if q, x and $ES>0$ (all are positive), $0<\beta<1$, $0<\gamma<1$ which implies that production is increasing in both the inputs.

The standard estimation procedure for estimation of production function is to take a log-log transformation of equation (2)

$$\log (q_i) = A + \beta \log (x_i) + \gamma \log (ES_i) + \varepsilon_i \quad (2)$$

where i denotes firm and ε is the error term. Because output produced by nature is a continuous endogenous variable, the dependent variable in (2) can be estimated using ordinary least-squares (OLS) regression. However, if inputs are endogenous, as is often the case with variable inputs, then the OLS estimates will be biased and estimation method will be replaced by model which captures endogeneity in the inputs. Such models include the instrumental variable models such as the *two stage least square* methods. The application of these methods requires instruments that are exogenous, as well as are valid and strong. These are variables that are strongly correlated with endogenous variables but uncorrelated with the error term and are not included in the structural equation (production function in this case).

I assume that environmental quality variable, represented by soil parameter, is endogenous in (2) (Soil quality gets affected by input uses along with the proximity to sacred groves.) and unbiased estimates of structural equation in (2) are estimated using system 2-stage least square method in the following way: Estimate the reduced form equation where endogenous environmental quality variable is a function of all exogenous variables, z_1 and x_1 using equation (3), where z_1 and x_1 are correlated with endogenous variable and uncorrelated with reduced form errors. Please note to assume a specific relationship between distance (z_1) and environmental quality, a log-linear relationship has been assumed unlike other exogenous factors (x_1) for which a log-log relationship has been assumed.

$$\log (ES) = \gamma_0 + \gamma_1 + z_1 + \gamma_2 \log (x_1) + \mu \qquad (3)$$

The predicted environmental quality is used to estimate the structural equation in (2). Equation (2) is weighted by the inverse of the sampling weights, to obtain weighted OLS (WLS) and weighted 2SLS (2SWLS) estimate. Note that weighted Ordinary Least Squares estimates are also derived for comparison. To account for the specific sampling technique, we use the weighted regression, where the estimated regression equation is weighted by the sampling weights- both the 2SLS and OLS equations are weighted by sample weights. For any collection of positive weights, a weighted least squares estimator can be defined. OLS is a specific instance in which all observations are given equal weight. Each squared residual is weighted by the inverse of the conditional variance of the error term given the data in the efficient technique Angrist and Pischke (2009). Instrumental variables in action: sometimes you get what you need. Mostly harmless econometrics: an empiricist’s companion. Weighted least square method does not affect the consistency of the estimator, however, it improves efficiency of the estimator.

2.2 Empirical models

The sampling unit for our analysis is a “household”. The dependent variable in a system estimation of two structural equations is given by total cereal yield value and total oilseeds yield value. The total cereal yield value is defined as the value of total yield of bajra and wheat in INR per hectare and the total oilseed yield value is defined as the total value of yield of castor, cotton, groundnut, mustard and sesame in INR per hectare. Our variable inputs are defined as labor-land ratio (persons per hectare) which is the agricultural labor force divided by operational land holding, irrigation (proxy for irrigation is defined as number of hours borewell used per day), proportion of manure to fertilizer (hectare in kilograms). Definition of variables is given in Table 1.

Structural equation is modeled as the following in equation (4) and equation (5). In this study, I have followed McArthur and McCord (2017) for defining variables in the empirical model

$$\log (\textit{Total Cereal Yield Value}) = A_1 + \beta_{11} \log (\textit{landlabor}) + \beta_{12} \log (\textit{manure / fertilizer}) + \beta_{13} \log (\textit{operational holding}) + \beta_{14} \log (\textit{irrigation}) + \beta_{15} \log (\textit{soil acidity}) + \mu_1 \qquad (4)$$

$$\log (\textit{Total Oilseed Yield Value}) = A_2 + \beta_{12} \log (\textit{landlabor}) + \beta_{22} \log (\textit{manure / fertilizer}) + \beta_{32} \log (\textit{operational holding}) + \beta_{42} \log (\textit{irrigation}) + \beta_{52} \log (\textit{soil acidity}) + \mu_2 \qquad (5)$$

Reduced form in equation is modeled as the following in equation (6) (Reduced form equation is an equation representing an endogenous variable as a function of “all exogenous variables”. Note that, all exogenous variables from structural equation are a part of the reduced form equation with an exception of the "exclusion restriction" given by the variable "distance" that helps identify structural coefficients in equation (4) and equation (5))

$$\log(\textit{soil acidity}) = \gamma_{01} + \gamma_{11}\,\textit{distance} + \gamma_{12}\,\textit{distance}^2 + \gamma_{13}\log(\textit{landlabor}) + \gamma_{14}\log(\textit{manure / fertilizer}) + \gamma_{15}\log(\textit{operational holding}) + \gamma_{16}\log(\textit{irrigation}) + \varepsilon \qquad (6)$$

Table 1 Definition of variables used to estimate a 2SLS mode.

Variable	Description
Proportion of manure to Fertilizer	Average manure to fertilizer used per hectare in kilograms
Labor: Land ratio	Natural logarithm of agricultural labor force divided by land planted to cereals (i.e. persons/ha) during the last cropping season.
Irrigation	Number of hours bore well used per day per hectare
Value of Oilseed Yield	Value of oilseeds yield per hectare in INR
Value of Cereal Yield	Value of Cereal yield per hectare in INR
Land per hectare	Operational Land holding in hectare
pH	pH is defined as the negative logarithm of the activity of hydronium ions in a solution. In soils, it is measured in a slurry of soil mixed with water using Electrode method (moles h+/ liter)
Distance	Distance of farmland from sacred groves (in kilometers)

Causal relationship between ecological benefits of sacred groves on farmland yield was done using Production Function Approach by examining if distance of farmland from sacred groves provides any yield benefits on farmland. *ES* in equation (4) is the measure of the environmental quality provided by the sacred groves which is the soil acidity of the farmland. The "optimal" soil pH is near to neutral at a pH value of 6.5. Below 6.5, soil becomes acidic and above 7.5 it becomes alkaline, both situations non-conducive for crop yield Shukla et al. (2004). Therefore, I have modified the variable to measure the ecosystem service effect on soil and defined it as soil acidity= (6.5-village-level pH). The environmental quality variable is defined at village-level; therefore, it was difficult to find much variability in the environmental quality variable. Out of all the soil parameters, soil acidity has considerable variability to explain variation in yield of cereals. In theory, soil pH is a significant parameter of soil indicating a proper growth and vegetation. For most crops, a range of 6 to 7.5 is best. If soil pH levels are too high or too low, it leads to deficiency of many nutrients, decline in microbial activity, decrease in crop yield, and deterioration of soil health USDA (2014). Therefore, soil acidity was included to represent soil quality of farmland. The summary statistics of soil parameters are shown in Table 2 and it shows the soil pH-level to have a standard deviation of 1.583, the highest compared to all other soil parameters. Moreover, high variability in pH is needed for yield of cereals. For example, the pH-level requirement for millet and maize is higher than the pH-level requirement for paddy and wheat. However, millet gives higher yield benefits in saline-clay loam soil, whereas, maize in warm and silt-loam type soil Wang et al. (2018). The endogenous environmental quality variable is defined as a function of distance of farmland (or villages) from sacred groves.

Table 2 Summary statistics of the soil parameters testified during the study.

Variable	Mean	Std. Dev.	Min	Max
Soil Moisture	.826	.322	.31	1.87
Soil Organic Carbon	.282	.153	.06	.63
Soil Organic Matter	1.069	.587	.2	2.4
Soil pH	4.580	1.583	2.67	6.3
Soil Salinity	1.697	.460	1	2

3 Results and Discussion

Table 3summarizes variables used in estimating a weighted two stage least square regression model. Table 4 presents results of the structural equation using both Weighted Least Square Estimates (WLS; Column 1 and Column 2) and Two-stage Weighted least square methods (2SWLS; Column 3 and Column 4). The estimate of soil acidity from WLS model is 0.019 % for cereals compared to 0.053% for cereals in 2SWLS respectively. A comparison of the soil acidity estimate shows a substantial downward bias (178.94%) [(0.053-0.019)/0.019)] for cereal yields in estimation using WLS as compared to 2SWLS. According to theory, I expect a negative sign on the coefficient of soil acidity - with a unit increase in soil acidity, agricultural yields reduce.

The endogeneity test suggests that environmental quality is an endogenous variable with a F-statistic value of 4.163 with 1 restriction and 175 degrees of freedom with a p-value of 0.04. In this study, I reject the null hypothesis (Zhang, 2022) of exogeneity of environmental quality (soil acidity) at 5% significance level.

Table 3 Summary Statistics of variables used to Estimate a 2SLS model.

Variable	Obs	Mean	Std. Dev.	Min	Max
Total cereal Yield (Kilograms/hectare)	192	8144.976	4277.472	0	26357.88
Total Oilseeds Yield (Kilograms/hectare)	192	9863.748	4764.46	0	23256.96
Total value of cereal Yield (INR/hectare)	192	146609.6	76994.49	0	474441.9
Total value of Oilseeds Yield (INR/hectare)	192	579452.8	265932.6	0	1335337
Labor (Person hours)	192	2060.651	665.977	0	3370
Operational Holding (Hectares)	192	1.908	0.665	0.607	3.440
Land labor (Person hours per hectare)	192	1196.994	500.69	0	2597.027
Fertilizer (Kilograms per hectare)	192	133.003	216.354	0	988.421
Manure (Kilogram per hectare)	192	126.700	204.658	0	988.421
Manure/Fertilizer	192	1.063	.530	.428	2.5
Irrigation (Number of hours borewell used per day)	192	7.286	1.416	0	9
Organic Carbon	192	.286	.152	.06	.63
pH	192	4.555	1.584	2.67	6.3
Soil Moisture	192	0.810	0.301	0.31	1.87
Distance	192	8.543	4.800	1	13.45

The reduced form coefficients and robust standard errors (parenthesis) for endogenous environmental variables is given in the following equation (7). Soil quality captured by the soil acidity level is endogenous to the farmer as it can be improved with the use of inputs as captured by equation (7). The statistically significant negative and positive coefficient on distance and the square of distance variables respectively imply that before the point of minimum, distance has a negative effect on soil acidity and after this point; distance has a positive effect on soil acidity. The relationship between distance and soil acidity has a U-shape. The turning point (or minimum of the function) is achieved at distance |-0.59|/(2*0.047) = 6 km. I have a U-shaped relationship between distance and soil acidity. An increase in distance from 6 to 7 kilometers, increases acidity by 100*{[-0.59+2*.047*(7)]} = 0.068*100 = 6.8% (100*{[-0.59+2*.047*(8)]} = 0.162*100 = 16.2%, 100*{[-0.59+2*.047*(9)]} = 0.256*100 = 25.6%, 100*{[-0.59+2*.047*(10)]} = 0.35*100 = 35.0%, 100*{[-0.59+2*.047*(11)]} = 0.444*100 = 44.44%, 100*{[-0.59+2*.047*(12)]} = 0.538*100 = 53.8%, 100*{[-0.59+2*.047*(13)]} = 0.632*100 = 63.2%).

Additionally, we can say that, as we go further from sacred grove, soil acidity increases after six kilometers. However, before six kilometers, say, going from two to three kilometers, away from sacred grove, soil acidity is declining (giving it a U-shaped). This is because of high-level of acidity due to lignite mining and other industrial pollution. Initially, at proximity soil acidity is higher. This is because of the propinquity of Ashapura chemical industry and also the lignite mine just at a distance of 2 km from the entrance of the reserve forest; it faces crises due to pollution and obstruction to nutrient replenishment. After 6 kilometers, for proximity to the sacred grove acidity declines. The statistically significant positive and negative coefficient on distance and the square of distance variables respectively imply that after the point of minimum, distance (sacred grove from farmland) has a positive effect on soil acidity and before this point; distance has a negative effect on soil acidity.

$$\log(\textit{acidity}) = \underset{(.602)}{.128} + \underset{(.076)}{.065}\log(\textit{land labor}) + \underset{(.053)}{.062}\log(\textit{fertilizer / manure}) + \underset{(.098)}{.044}\log(\textit{irrigation})$$

$$-\underset{(.066)}{.035}\log(\textit{operational landholding}) - \underset{.049)}{.592}\,\textit{distance} + \underset{(.003)}{.047}\,\textit{distance}^2 \qquad (7)$$

The estimates of structural equation in Col. 3, Table 3 suggest that soil acidity reduces total cereal productivity. Lower soil acidity improves environmental quality that increases the cereal yield. This is consistent with the findings from studies (Leech et al., 1998; Levers et al., 2016) for impact of pH on cereal yield. The soil acidity is individually statistically significant, at 1% significance level. The environmental quality variable in the cereal yield estimated equations suggest that higher soil acidity by 1% reduces value of yield by 0.05% for cereals. For, the villages, going from 6-7 km, say, in kilometer radius, 0.003% can be attributed to proximity to sacred groves for cereal and oilseed yield respectively. We get statistical significance for the causal relationship between soil acidity and cereal yield value and NOT for oilseed yield value. We estimated crop-wise structural equation (reported in the Appendix) - however, our findings in terms of statistically significant causal relationship are consistent with aggregate results. Therefore, our evidence and inference are restricted to cereal yield value.

Comparing structural coefficients in Col. 3, and Col. 4 in Table 3 - 1% increase in irrigation increases value of total cereal yield by 0.69% and 1% for oilseeds. Farmers prefer to grow cereals such as rice, sugarcane, cotton, vegetables in irrigated land, setting apart rainfed/dryland to oilseeds as oilseeds are relatively fewer sensitive crops. Therefore, irrigation has higher yield effect for oilseeds as compared to cereals. The percentage of area under irrigation in oilseed crops stands at less than 30 per cent, which is very less as compared to area under cereal crops. Among the three major oilseed crops, the area under irrigation is high for rapeseed-mustard 72% (Vashishtha, 2002). Therefore, yield gap in oilseed with irrigated farmland is much higher as compared to rainfed cropped area. 1% increase in manure applied as a proportion of fertilizer increases total cereal yield value by 0.44% and oilseed yield 0.14%. Percentage fertilizer requirement of cereals such as wheat and paddy are the highest and since organic manure also improves the efficiency of mineral fertilizer use, productivity benefits of manure is much higher for cereals as compared to oilseeds (FAO, 2005). 1% increase in land-labor ratio increases total oilseed yield value 0.16%.

Table 4 Regression results of ordinary least square estimates compared with a 2-Stage Least Square method.

VARIABLES	(1) WLS-cereal 1	(2) WLS-seeds 2	(3) 2SWLS-cereal 3	(4) 2SWLS-seeds 4
Land-labor	-0.0636	0.133	-0.0671	0.162
	(0.121)	(0.132)	(0.119)	(0.128)
Manure/fertilizer	0.464***	0.115	0.458***	0.139
	(0.0763)	(0.115)	(0.0744)	(0.111)
Irrigation	0.699***	0.976***	0.686***	1.035***
	(0.190)	(0.223)	(0.187)	(0.213)
Operational holding	-0.662***	-0.101	-0.648***	-0.0641
	(0.104)	(0.143)	(0.102)	(0.136)
Acidity	-0.0199	0.0278	-0.0530*	0.0567
	(0.0282)	(0.0397)	(0.0280)	(0.0446)
Constant	11.25***	10.32***	11.31***	9.950***
	(1.003)	(1.153)	(0.984)	(1.099)
Observations	181	181	181	181
R-squared	0.417	0.147	0.412	0.142

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

I use the following equation (8) to calculate returns to scale for cereal production (Lanfranchi et al., 2014)

$$\frac{Y}{K} = AK^{\alpha+\beta+\gamma+\delta+\phi-1}\left(\frac{L}{K}\right)^{\beta}\left(\frac{f}{K}\right)^{\gamma}\left(\frac{i}{K}\right)^{\delta}\left(\frac{PH}{K}\right)^{\phi} \quad (8)$$

I get decreasing returns to scale for cereal yield (-0.624), (-0.0671 + 0.458 + 0.686 - 0.648 - 0.053-1 = -0.6241).

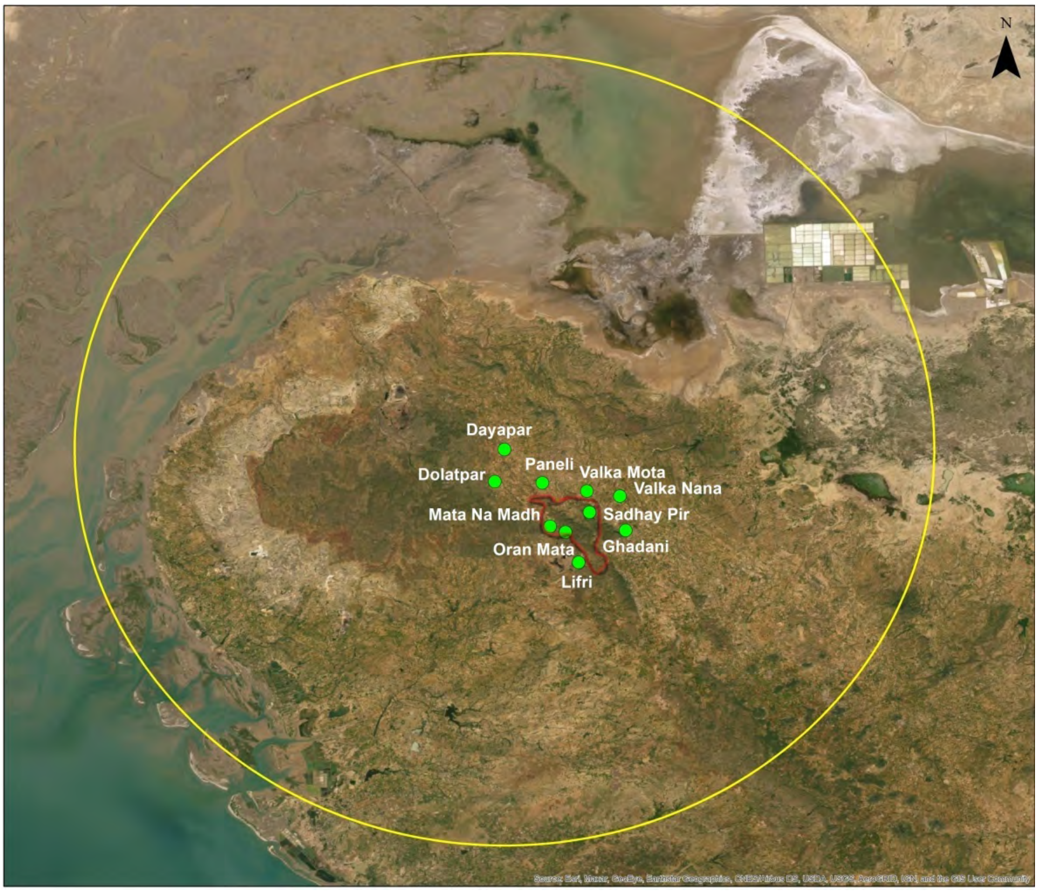

Fig. 2 Distance of villages from the selected sacred groves.

The GIS map shows the topography of the area at a distance of 10 km from the surveyed villages (Fig. 2). It is quite evident that other than Gugaliyana Reserve Forest of 2229.26 hectare (demarcated in blue in Fig. 2) there is no other forest or vegetation patch present near to the villages. Also, being an arid biogeographic province, the topography shows a deserted land surrounding the study area. Moving away from sacred grove resulting in proximity to other forests is therefore not applicable.

However, one can think that the impact of Gugaliyana could be confounding the impact of sacred groves on yield, but I hope to have minimized it because of the following reasons. As evident from Fig. 2, the distance of villages from sacred groves are similar to their distances from Gugaliyana boundary, i.e., villages closer to sacred groves are closer to Gugaliyana and similar for far off villages. The distance is likely capturing the combined impacts of sacred groves and Gugaliyana reserve forest, but the forest is a patch of dry land with invasive *Prosopis juliflora* as shown below (Fig. 3a) and may not provide yield enhancing ecosystem services. The only green patches in the forest are the sacred groves (Fig. 3b).

Fig. 3a Vegetation in sacred groves (outside) (Source: Field Survey).

Fig. 3b Vegetation in sacred groves (inside) (Source: Field Survey).

The first four pictures are from the Gugaliyana and the last two are of the sacred groves. The specific feature that is likely to disentangle the ecosystem services provided by the sacred groves from the reserve forest is the presence of the age-old wells in the sacred grove premises that are conserved despite subsequent drought years. The wells act as fragile underground water aquifers which helps in the replenishment of the soil nutrients. Additionally, rainwater gets stored due to fractures and fishers in the soil and overall land which further leads to the recharge of groundwater (Central Groundwater Report, 2013, http://cgwb.gov.in/AnnualReports/Annual%20Report-2013-14.pdf). For the rest of the portion of Gugaliyana reserve forest it is only through soil moisture that the water availability is sustained in a subliminal way.

The Total Economic Value in terms of improved cereal yield value can be calculated by the percentage of improvement in cereal yield value attributed to proximity to sacred groves (0.003%) of cereal yield value evaluated at the average (146609.6 INR/hectare) multiplied by average operational land holding and total households in the selected villages. The improvement in cereal yield value attributed to proximity to sacred groves equals 4.39 INR/hectare. Taking the average operational land holding to be 2 hectares and total number of households in the selected villages to be 2222, total economic value in terms of improved cereal yield value attributed to sacred groves for the selected village = 19509 INR/annum.

4 Discussion

Despite the fact that the literature on ecosystem services has grown significantly over the previous three decades, the idea remains controversial (Barnaud and Antona, 2014). The term "ecosystem service" was coined by early proponents of the concept (Ehrlich and Mooney, 1983; Westman, 1977) to describe the loss of natural resources as a result of anthropogenic activities that hampered ecosystems' ability to perform essential services. These authors, as well as others (Daily, 1997; Chapin et al., 2000), argue that such services are offered by nature and contribute considerably to human well-being in a variety of ways. Others argue that humans' environmentally conscious actions facilitate the provision of ecosystem services (Gordon et al., 2011; Sunderlin et al., 2005; Wunder, 2007), a debate that aligns with researchers' motivation to develop and apply an economic valuation of ecosystems and the services they provide (Costanza et al., 1998; Woodward and Wui, 2001). Following that, policy mechanisms such as payments for ecosystem services (Wunder, 2007, 2008) were developed to financially compensate land managers for protecting ecosystem services and avoiding detrimental land-use practices. Researchers have lately proposed that ecosystem services are co-produced by socio-ecological processes—that is, a combination of natural, financial, technological, and social capital—and that appropriation often necessitates some degree of human intervention (Pattanayak, 2009; Biggs et al., 2015; Palomo et al., 2016).

5 Conclusions

Traditionally, sacred groves have been the cultural centers for communities and the ecosystem providing many visible provisioning services like medicinal herbs, healing facilities, water, etc. to nearby communities. This study identified and valued invisible supporting services like enhanced soil quality that is facilitating agricultural productivity and helping the farmers of the surrounding villages. Sacred groves are in deteriorating conditions due to anthropogenic pressures like excessive grazing, biomass collections, negligence, etc. and the study findings provide enough evidences to reverse the trend and make people the agents of conservation.

I have compared the results from this study with studies that have captured yield benefits of forests-related environmental services. The magnitude of yield benefits from sacred groves is even higher as compared to forests. Yin and Hyde (2000) found the yield benefits of 0.01% as compared to an average 0.05% in this study, out of which, 0.003% is attributed to sacred groves. This might be because soil parameters are highly correlated with distance to sacred groves and farmland are in proximity to these groves. Ren et al. (2019) found that intensity of variable inputs such as chemical fertilizers is negatively related to farm size, i.e., proportion of variable inputs such as fertilizers are lower on larger farms than smaller farms. As less-intensive fertilizer usage increases soil quality of farmland, for our sample, where the average household surveyed are small farmers, I find the magnitude of marginal returns for inputs is lower.

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