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Meghana SV

PG Scholar, Department of Agricultural Economics, KSNUAHS, College of Agriculture, School of Post Graduation Studies, Main Campus, Iruvakk, Shivamogga, Karnataka, India

Kiran Kumar R Patil

Assistant Professor, Department of Agricultural Economics, KSNUAHS, College of Agriculture, School of Post Graduation Studies, Main Campus, Iruvakk, Shivamogga, Karnataka, India

Basavaraj I Halingali

Professor, Department of Agricultural Statistics, KSNUAHS, College of Agriculture, School of Post Graduation Studies, Main Campus, Iruvakk, Shivamogga, Karnataka, India

Basamma Aladakalli

Assistant Professor, Department of Agricultural Engineering, KSNUAHS, College of Agriculture, School of Post Graduation Studies, Main Campus, Iruvakk, Shivamogga, Karnataka, India

Dhananjaya Swamy PS

Assistant Professor, Department of Agricultural Economics, College of Agriculture, Hassan, Karnataka, India

Corresponding Author: Meghana SV

PG Scholar, Department of Agricultural Economics, KSNUAHS, College of Agriculture, School of Post Graduation Studies, Main Campus, Iruvakk, Shivamogga, Karnataka, India

Quantification of reinvestment determinants of borewells in hard rock areas of Karnataka

Meghana SV¹, Kiran Kumar R Patil², Basavaraj I Halingali³, Basamma Aladakalli⁴, Dhananjaya Swamy PS⁵

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ABSTRACT

Borewell failure represents a major hydrogeological uncertainty and economic risk for groundwater-dependent agriculture in hard-rock regions, as farmers may be required to make additional investments to secure a dependable source of irrigation. Against this backdrop, the present study examined the determinants of additional borewell investment following initial borewell failure in the Malnad region of Karnataka, India. Primary data were collected from 140 farms comprising 50 drip-irrigated farms (DIF), 50 sprinkler-irrigated farms (SIF) and 40 conventional-irrigated farms (CIF) in Shivamogga and Uttara Kannada districts. The Tobit model was estimated using EViews software to examine the influence of irrigation technology, groundwater use, variable cost of groundwater irrigation, successful years of borewell operation and gross irrigated area on additional borewell investment. The results indicated that groundwater use, variable cost of groundwater and gross irrigated area had a positive and significant association with additional borewell investment, while the number of successful borewell years showed a negative relationship. The predicted investment on additional or replacement borewells following initial failure was ₹2,84,241.36 per farm under DIF, ₹2,64,868.54 under SIF and ₹52,126.23 under CIF. The findings highlight that borewell failure creates a substantial and technology-specific reinvestment burden, emphasizing the importance of efficient groundwater use and improved irrigation management for reducing farmers' exposure to repeated groundwater-development investments.

Keywords: Borewell longevity, Climate-resilient practices, EViews software, Initial borewell failure, Tobit model

Introduction

Groundwater, hailed by UNESCO *et al.* (2022) [1] as the “invisible” and indispensable resource, is a vital yet hidden natural resource that underpins drinking water supplies, food security, ecosystems and socio-economic development worldwide (UNESCO *et al.*, 2022; Gleeson *et al.*, 2020) [1, 2]. As a major source of water for irrigated agriculture, increasing demands for food, livestock and commercial or horticultural crops have intensified dependence on groundwater, particularly in developing countries (IWMI, 2007; UNESCO, 2022) [1]. Consequently, India has emerged as the world's largest consumer of groundwater, accounting for approximately 25.00 per cent of global groundwater extraction annually (India Observatory, 2024). However, a large proportion of the country is underlain by hard-rock formations, where groundwater occurrence and movement are largely controlled by weathered and fractured zones, making groundwater availability spatially heterogeneous and uncertain (Narasimhan, 2006; Sharma and Kumar, 2022) [3]. This vulnerability is particularly evident in Karnataka, where the stage of groundwater extraction increased from 66.26 per cent in 2023 to 68.44 per cent in 2024, while annual groundwater recharge declined from 18.93 to 18.74 billion cubic metres (bcm) (CGWB, 2024). Increasing groundwater stress can lead to declining water levels and well yields, thereby increasing the cost of groundwater abstraction and irrigation (Anantha, 2013; UNESCO *et al.*, 2022) [4, 1]. Under such uncertain hydrogeological conditions, farmers are increasingly required to bear substantial capital expenditure on borewell drilling and, when initial wells fail, on additional wells to secure a dependable source of irrigation (Nagaraj *et al.*, 1994; Patil *et al.*, 2019) [5, 6].

Borewell failure therefore represents both a hydrogeological uncertainty and a substantial economic risk for groundwater-dependent agriculture, particularly in hard-rock regions where the probability of locating a productive aquifer is uncertain (Nagaraj *et al.*, 1994; Bassi *et al.*, 2008) [4, 7, 5, 6]. Failed drilling creates sunk investment and increases the effective cost of establishing a functioning groundwater irrigation system, while repeated drilling can further increase the capital burden on farm households (Nagaraj *et al.*, 1994; Patil *et al.*, 2019) [5]. Evidence from Karnataka indicates that the probability of successful well drilling has declined over time, with investment in failed wells constituting a substantial share of total expenditure on groundwater development (Patil *et al.*, 2019) [6]. Groundwater depletion and well interference may further induce farmers to deepen existing wells or drill additional borewells to sustain irrigation, thereby affecting the cost and returns from groundwater irrigation (Anantha *et al.*, 2011; Anantha, 2013) [4, 8]. Well failure can conse

quently reduce the extent of irrigation, affect crop productivity and returns, and increase the economic burden of groundwater-dependent cultivation, with small farmers being particularly vulnerable to resource scarcity (Bassi *et al.*, 2008; Anantha, 2013) [7, 4]. However, the magnitude of additional investment following an initial borewell failure is unlikely to be uniform across farms and may vary with the irrigation technology adopted, quantity of groundwater used, variable cost of water, longevity of successful wells and extent of irrigated area. While previous studies have examined well-failure probability, groundwater externalities and the economic consequences of groundwater exploitation, relatively limited attention has been given to the farm-level determinants of additional borewell investment conditional on initial failure (Nagaraj *et al.*, 1994; Patil *et al.*, 2019 [6]; Anantha, 2013). Identifying these determinants is therefore important for understanding farmers' investment responses to groundwater uncertainty and the economic persistence of groundwater-dependent agriculture in hard-rock environments.

The Malnad region of Karnataka provides an important setting for examining this investment response because groundwater occurrence is largely controlled by weathered and fractured hard-rock formations, making well productivity spatially variable and borewell drilling inherently uncertain (Government of Karnataka, 2014; Narasimhan, 2006) [9, 3]. Despite receiving relatively high rainfall, the region has experienced increasing dependence on groundwater irrigation for commercial and perennial crops, accompanied by considerable borewell investment and well failures (Patil *et al.*, 2026) [10]. Recent evidence from the Malnad region reported initial borewell failure of 41.49 per cent and premature failure of 4.26 per cent, highlighting the uncertainty associated with groundwater development even in a high-rainfall environment (Patil *et al.*, 2026) [10]. These characteristics make the region particularly relevant for assessing how farmers respond economically to unsuccessful groundwater development. However, existing studies in the region have largely focused on groundwater availability, well success and failure, irrigation economics, groundwater externalities and sustainability, while limited empirical attention has been given to the factors influencing the magnitude of additional borewell investment following initial failure (Anantha, 2013; Patil *et al.*, 2019) [4, 6]. Against this background, the present study examines the determinants of additional borewell investment following initial borewell failure in the Malnad region of Karnataka using a Tobit model. Specifically, the study evaluates the influence of irrigation technology, groundwater use, variable cost of water, successful-well years and gross irrigated area on the magnitude of additional investment.

Materials and Methods

Study area

The study was undertaken in the Malnad region of Karnataka, a predominantly hard-rock area characterized by undulating terrain, lateritic and red soils, high surface runoff and limited effective groundwater recharge. In recent years, changes in the cropping pattern from traditional paddy cultivation towards relatively high-value commercial crops such as arecanut and ginger have increased irrigation water requirements and, consequently, farmers' dependence on groundwater. The growing reliance on borewells to meet the irrigation requirements of these crops has intensified pressure on groundwater resources and increased the uncertainty associated with obtaining a productive and sustainable irrigation source. Under such conditions, borewell failure may compel farmers to undertake repeated drilling attempts before securing a successful well, thereby increasing the additional investment required for establishing functional groundwater infrastructure. The resulting variation in investment among farmers provides an important basis for examining the factors associated with additional borewell expenditure following initial failure. Accordingly, the Malnad region, comprising Shivamogga and Uttara Kannada districts and falling under the Hilly Zone of Karnataka, was selected as

the study area to investigate the farm-level determinants of additional borewell investment contingent upon initial borewell failure.

Sampling framework and data

The study was conducted in Shivamogga and Uttara Kannada districts of the Malnad region of Karnataka. Villages within the selected districts were randomly selected, and farm households dependent on groundwater irrigation for agricultural production were identified. From the selected villages, farmers using groundwater through drip, sprinkler and conventional irrigation systems were selected using random sampling. The sampled farms were subsequently post-stratified according to the irrigation technology adopted into Drip Irrigated Farms (DIF), Sprinkler Irrigated Farms (SIF) and Conventional Irrigated Farms (CIF). A total of 140 farms were selected, comprising 50 DIF, 50 SIF and 40 CIF farms.

Primary data were collected from the selected farm households using a well-structured and pre-tested interview schedule for the agricultural year 2025–26. Detailed information was collected on the number of borewells drilled, their drilling year and functioning status, depth and yield of functioning borewells, expenditure on borewell drilling and casing, and investment in irrigation infrastructure. Information was also collected on the type of irrigation technology adopted (drip, sprinkler or conventional), quantity of groundwater used per farm, variable cost of groundwater irrigation, number of years for which the successful borewell had remained functional, gross irrigated area, cropping pattern and other relevant farm-level characteristics. Particular attention was given to the number and status of failed borewells, investment incurred on failed and functioning borewells, and the additional investment made in subsequent borewells following initial failure.

Analytical tools employed

Concept of borewell failure and economic life of borewells

Initial failure of a borewell refers to a borewell that did not yield any groundwater at the time of drilling or thereafter. Premature failure refers to the failure of a borewell before completing its subsistence life or Pay Back Period (PBP). Economic life/age of a borewell refers to the number of years for which the borewell yielded groundwater beyond the PBP, whereas subsistence life of a borewell refers to the number of years for which the borewell yielded groundwater up to the PBP. The PBP was calculated by dividing the total investment incurred on drilling, casing, IP set, conveyance structure, storage structure, drip/sprinkler structure and electrification by the annual net returns obtained per farm. It indicates the number of years required for the investment to recover its cost. The underlying hypothesis was that an irrigation borewell was considered to have served its purpose once it had generated sufficient returns to recover the total investment incurred for its establishment. Thus, the PBP represents the period required for the borewell irrigation investment to recover its initial cost. In the present study, no premature borewell failures were observed among the sampled farms. Therefore, the econometric analysis was restricted to farms experiencing initial borewell failure.

Costing of irrigation water

The annual irrigation cost was estimated for each borewell on the farm and aggregated across borewells, and the total cost was apportioned among crops according to the volume of groundwater used by each crop (Chandrakanth *et al.*, 2018; Patil *et al.*, 2016; Rohith *et al.*, 2015) [11, 12, 13].

Cost of irrigation per acre-inch = [Total annual cost of irrigation]/[volume of water used for the crop in acre inches of groundwater used].

Factors influencing investment on additional or new borewell contingent upon initial failure/s

The present study employed the Tobit model to determine the factors influencing investment in additional/new borewells following initial borewell failure. The model was estimated using EVIEWS software to

examine the influence of irrigation technology, groundwater use, variable cost of groundwater irrigation, successful years of borewell operation and gross irrigated area on additional borewell investment.

The Tobit model, originally proposed by Tobin (1958) [14], is appropriate for analysing a dependent variable that is censored at a specified limit. The model has also been applied in agricultural economics to examine the determinants of farm-level investment decisions, including farmers' soil and water conservation investments (Pender *et al.*, 1998) [15].

The investment on irrigation well per farm contingent upon both initial borewell/s was hypothesized to be Tobit dependent upon the groundwater used for irrigation per farm, variable cost of irrigation, the number of successful years of operation of borewell/s, dummy variables to represent borewell farmers with drip irrigation, sprinkler and conventional irrigation. Using the data from the sample of 140 farmers, the subsample of farmers who suffered only initial failure was 66.

The Tobit model was specified as Investment on borewell/s per farm contingent upon initial failure of borewell/s

$$I = \alpha + \beta_1 D_1 + \beta_2 D_2 + \beta_3 X_1 + \beta_4 X_2 + \beta_5 X_3 + \beta_6 X_4 + \varepsilon \dots (1)$$

where, I = Investment on borewell/s per farm contingent upon initial failure/s of borewell/s. D_1 represents dummy for drip technology (farms with drip irrigation took the value 1 and farms with conventional irrigation took the value 0).

D_2 represents dummy for sprinkler technology (farms with sprinkler technology took the value 1 and farms with conventional irrigation took the value 0)

X_1 = total groundwater used per farm in acre inches

X_2 = Variable cost of groundwater

X_3 = Number of successful borewell years of operation on the farm

X_4 = Gross irrigated area per farm in acres

ε = stochastic error term

Results and Discussion

The Investment on additional or new borewell/s per farm contingent upon initial failure of borewell/s was hypothesized to be a Tobit dependent upon the groundwater used for irrigation per farm, gross area irrigated per farm, variable cost of irrigation, the number of successful years of operation of borewell/s, dummy variable to represent drip and sprinkler technologies. The unrepresented category of farmers represents the control farmers for contrast. If the Tobit regression coefficient for dummy variable is negative, it is considered as the savings realized in investment on new or additional well, after suffering from initial well failure. If the Tobit regression coefficient for dummy variable is positive, this is considered as the amount necessary to be invested due to the concerned independent variable. This is due to the context in which the Tobit function was estimated. The results (Table 1) indicated that the log likelihood value of -1053.93 has proved the goodness of fit test of the model. The use of the Tobit model for analysing farm-level investment decisions is supported by earlier agricultural economic studies, where Tobit regression has been used to examine the determinants of farmers' investment decisions (Pender *et al.*, 1998) [15]. The coefficient of intercept was negative with the magnitude -100035.7, indicating that the control farmers who suffer from initial well failure save an amount of ₹100035.7 by not investing on additional or new borewells. The borewell farmers with drip irrigation could save an amount of ₹44,974.56 and farmers with sprinkler irrigation could save an amount of ₹30,905.14 on drilling new well/additional well due to initial failure of borewell. This finding suggests that the adoption of improved irrigation technologies is associated with lower investment requirements for additional groundwater sources following borewell failure, as these technologies can improve the efficiency of irrigation water use. Evidence from Karnataka shows that drip irrigation reduces groundwater use per acre, although groundwater use per farm may not necessarily decline because of greater irrigation intensity (Kabbur *et al.*, 2023) [16].

If the variable cost of groundwater increases by one rupee, the investment on a new borewell increases by ₹48.01 irrespective of irrigation

technologies. The groundwater which was hitherto a free natural resource could no longer be free since farmers incur huge amount of investment in order to get successful borewell. Hence, every rupee increase in variable cost of groundwater signals scarcity of the resource forcing farmers to bear additional investment. This positive relationship is consistent with the economic evidence from Karnataka that farmers bear substantial costs associated with groundwater development, particularly because of repeated well failures and investment in groundwater wells (Chandrakanth *et al.*, 2018) [11]. Similarly, for an increase in gross irrigated area, investment on an additional or new borewell increases by ₹39,700.50. Additional gross irrigated area imposes additional pressure on groundwater and have repercussion on success of borewell and hence, the additional cost. The positive relationship between farm characteristics and investment is supported by Pender *et al.* (1998) [15], who found that farm and resource-related characteristics influenced farmers' investment decisions.

Table 1. Determinants of investment on additional borewells contingent upon initial borewell failure/s in the Malnad region of Karnataka ($n = 140$)

Particulars	Magnitude
Intercept	-100035.70 (0.11)
Dummy for Drip technology(D_1)	55061.14 (0.28)
Dummy for Sprinkler technology(D_2)	69130.56 (0.17)
Groundwater used per farm (acre inches) (X_1)	808.23* (0.02)
Variable cost of water (₹)(X_2)	48.01* (0.00)
Number of successful well years(X_3)	-2812.59 (0.59)
Gross irrigated Area (acres)(X_4)	39700.50 (0.00)
Log Likelihood	-1053.93

Note: Figures in the parentheses indicate 'p' value

* indicates five per cent level of significance

The coefficient of the life of the functioning borewell was negative, indicating that each additional year of successful well operation reduces the expected investment on new/additional well by ₹2812.59. If the drilled borewell functions for an additional year, farmers could postpone drilling of a borewell and relieve the physical and economic scarcity of groundwater. This negative relationship is economically consistent with the role of existing productive assets in determining subsequent farm investment. Pender *et al.* (1998) [15] reported that existing land investments were among the factors influencing subsequent investment decisions. For every acre-inch of water used per farm, the investment on new borewell upon initial failure/s increases by ₹808.23. The positive relationship indicates that greater groundwater use is associated with a greater requirement for securing a dependable groundwater source. This is particularly relevant in the Malnad region, where recent evidence has documented substantial groundwater extraction, initial borewell failure and investment in groundwater irrigation structures (Patil *et al.*, 2026) [10]. Based on the estimated Tobit equation and the mean values of the explanatory variables, the predicted investment on additional or replacement borewells contingent upon initial borewell failure was ₹2,84,241.36 per farm in case of DIF, ₹2,64,868.54 in case of SIF and ₹52,126.23 in CIF. The substantial difference in predicted investment across irrigation technologies highlights the variation in groundwater-related investment requirements among different irrigation systems, which is also consistent with evidence that irrigation technology and groundwater-use

patterns influence the economic outcomes of groundwater irrigation (Kabbur *et al.*, 2023; Fishman *et al.*, 2023) [16, 17].

Conclusion

The study revealed that initial borewell failure imposes a substantial economic burden through additional investment in groundwater development. Groundwater use, variable cost of water and gross irrigated area positively influenced additional borewell investment, while longer successful borewell operation reduced the investment requirement. The predicted investment was ₹2.84 lakh per farm under DIF, ₹2.65 lakh under SIF and ₹0.52 lakh under CIF. The findings highlight considerable variation in reinvestment requirements across irrigation technologies. Overall, the study underscores the need for efficient groundwater use and improved irrigation management to reduce farmers' exposure to repeated borewell investment.

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