

When the Sky Opens: How Rainfall Drives Fertilizer Demand in Dharwad

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Abstract—Fertilizer demand in India rises and falls with the monsoon. This paper studies eight years of point of sale fertilizer sales data from Dharwad, Karnataka, along with matching daily rainfall records. Monthly sales are compared with monthly rainfall for the period 2018 to 2025. Simple statistical tools such as correlation, regression and t-tests are used. Results show that fertilizer sales are far higher in months with rain than in dry months. The kharif season alone accounts for almost sixty percent of the total sales in the study years. Urea and NPKS are the most rain-sensitive products, while SSP shows almost no link with rainfall. A short one-month lag effect is also found for Urea and NPKS. These findings can help dealers and policy makers plan stock and credit around the monsoon calendar rather than around calendar months alone.

Keywords—agribusiness, fertilizer demand, kharif season, monsoon, point-of-sale data, rainfall, rabi season

I. INTRODUCTION

Agriculture remains the backbone of the Indian economy, engaging nearly half of the country's workforce and shaping food security, rural incomes and allied industries such as fertilizer manufacturing and retail trade. Among the inputs that determine crop productivity, chemical fertilizers occupy a central place: balanced and timely fertilizer application is one of the strongest levers available to raise foodgrain yield per hectare [2]. India's fertilizer consumption has grown steadily over the past decades, but this growth has been geographically and seasonally uneven, closely tracking the pattern of the monsoon and the areas brought under irrigation [2], [5]. Ensuring that fertilizer is available to farmers at the right time and in the right place therefore remains a persistent policy and supply-chain challenge, one that requires a strategic shift in how fertilizer response is planned and monitored [3].

Karnataka is one of the states where this seasonal dependence is particularly visible. Dharwad district, located in the northern dry zone of Karnataka, has an agro-climatic profile dominated by the southwest monsoon, with the bulk of annual rainfall concentrated between June and September [15].

The district's cropping system is built around rainfed kharif crops such as cotton, maize, soybean and pulses, which places fertilizer demand in Dharwad on a tight seasonal calendar dictated by the arrival and progress of the monsoon rather than by the standard January-to-December cycle used in most business planning. This dependence mirrors the wider link that has been documented between Indian summer monsoon rainfall and kharif foodgrain output [6], [8], and it is this local, monsoon-driven character of demand that motivates a focused, data-driven study of Dharwad district rather than a generic national-level analysis.

Fertilizer is one of the most important inputs in Indian farming. Its use goes up sharply once the monsoon begins, since rain decides when farmers sow their crops and how much water is available for nutrient uptake in the soil [1], [2]. Past studies have shown that rainfall and irrigation both push up fertilizer use across Indian districts and that a poor monsoon in one year can lower fertilizer demand in the following year [1].

Fertilizer demand does not depend on rainfall alone. It also depends on the government subsidy structure, dealer credit lines, seed availability and the price of the crop the farmer expects to sell later [3]. Even so, rainfall remains one of the few factors that a dealer or policy maker can watch and react to on short notice, since rainfall bulletins are published daily by the India Meteorological Department. This makes rainfall a practical variable to study even though it is not the only driver of demand.

Karnataka, and Dharwad district in particular, depends heavily on the southwest monsoon for its kharif crops. Past work on Indian monsoon rainfall shows that kharif foodgrain yield moves closely with June to September rainfall, while rabi yield depends more on stored soil moisture than on rain falling in that season itself [6], [8]. Since crop growth and fertilizer use are closely linked, a similar seasonal pattern is expected in fertilizer sales. Studies from other rainfed regions of India also show that uneven rainfall distribution, and not only the total seasonal amount, changes farmer decisions on sowing and input use [13].

Since 2018, most retail fertilizer sales in India are recorded through Point of Sale (PoS) machines under the Direct Benefit Transfer (DBT) scheme. Every bag sold to a farmer is logged against an Aadhaar or Kisan Credit Card number before the government releases subsidy to the company [11], [14]. This gives a reliable, transaction-level record of fertilizer demand that was not available before DBT started. Earlier studies on fertilizer sales in India had to depend on state-level annual totals, which hide the month-to-month and product-wise detail that a rainfall study needs [12].

This paper uses eight years of such PoS data from Dharwad along with daily rainfall records to study one simple question: how strongly does rainfall drive fertilizer demand and does this differ by product, season and lag month? Five specific objectives are examined: (i) the overall statistical link between monthly rainfall and total fertilizer sales, (ii) whether this link is the same for every product, (iii) how the kharif, rabi and summer cropping seasons differ in sales and rainfall, (iv) whether completely dry months behave differently from months with even a small amount of rain and (v) whether rainfall in one month can predict sales in the following month. The results are meant to help agri-input dealers and policy makers plan stock and credit better around the monsoon calendar.

Problem Statement and Objectives of the Study

Despite the well-established qualitative link between the monsoon and Indian farm input use, agri-input dealers and district-level policy makers in places like Dharwad still largely plan fertilizer stock, logistics and dealer credit around fixed calendar months rather than around the actual, and often uneven, progress of rainfall. This mismatch creates two recurring problems in practice: dealers are frequently caught under-stocked when rain arrives early or in a burst, and they carry unsold, credit-financed inventory when a season turns dry. The core research problem addressed in this study is therefore: how strongly, and through which products and seasons, does rainfall actually translate into fertilizer demand in Dharwad district, and can this relationship be expressed in a form that is simple enough for a dealer or planner to act on with only publicly available rainfall bulletins?

To address this problem, the study is guided by the following specific objectives:

- 1) To examine the overall statistical relationship between monthly rainfall and total fertilizer sales in Dharwad district.
- 2) To assess whether this rainfall-sales relationship differs across major fertilizer products (Urea, DAP, MOP, NPKS and SSP).
- 3) To compare fertilizer sales and rainfall across the kharif, rabi and summer cropping seasons.
- 4) To evaluate whether completely dry months behave differently from months with even limited rainfall.
- 5) To test whether rainfall in one month has predictive value for fertilizer sales in the following month (lag effect).

II. STUDY AREA, DATA AND METHOD

A. Study Area and Data

The secondary data of monthly fertilizer sales figures were taken from PoS records for Dharwad district from the Joint Directorate of Agriculture, Dharwad. Five major products were studied: Urea, DAP, MOP, NPKS and SSP, along with their combined total. Daily rainfall records for eight years were collected from the North Karnataka Agrometeorological Forecasting and Research Centre (NKAFC) for Dharwad, and were summed into monthly totals. The final dataset covers ninety-three months, from April 2018 to December 2025. Both series were checked for missing values and unusual entries before analysis and no month had to be dropped from the study period.

B. Method of Analysis

Months were also classified into the three cropping seasons commonly used in Indian agriculture: kharif (June to October), rabi (November to March) and summer (April and May). This classification follows the same broad calendar used in earlier work on monsoon rainfall and foodgrain yield [6], [8], [10].

C. Model Specification

The relationship between monthly rainfall and total fertilizer sales was modelled using a simple ordinary least squares (OLS) linear regression of the form:

$$Sales_t = \beta_0 + \beta_1 \cdot Rainfall_t + \varepsilon_t \quad (1)$$

where $Sales_t$ is total fertilizer sales (tonnes) in month t , $Rainfall_t$ is total rainfall (mm) in month t , β_0 and β_1 are the intercept and slope coefficients estimated from the data, and ε_t is the residual error term. The strength of association between rainfall and sales, both overall and product-wise, was additionally measured using the Pearson product-moment correlation coefficient and the Spearman rank correlation coefficient:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{[\sum(x_i - \bar{x})^2 \cdot \sum(y_i - \bar{y})^2]}} \quad (2)$$

Differences in mean sales between groups of months (e.g. dry versus wet months, or seasonal groups) were tested for statistical significance using Welch's two-sample t-test, which does not assume equal variances between groups:

$$t = (\bar{x}_1 - \bar{x}_2) / \sqrt{(s_1^2/n_1 + s_2^2/n_2)} \quad (3)$$

D. Model Evaluation Metrics

To evaluate how well the fitted regression line represents the observed data, two standard error-based diagnostic measures were used in addition to the coefficient of determination (R^2): the Root Mean Square Error (RMSE) and the Bias (Mean Error). RMSE summarizes the typical magnitude of prediction error in the same unit as sales (tonnes), and is defined as:

$$RMSE = \sqrt{[(1/n) \cdot \sum (y_i - \hat{y}_i)^2]} \quad (4)$$

where y_i is the observed sales value, $\hat{y}_i$ is the sales value predicted by the regression model for the same month, and n is the number of months. A lower RMSE indicates that the model's predictions lie closer to actual observed sales. Bias measures whether the model systematically over- or under-predicts sales, and is defined as the mean signed error:

$$Bias = (1/n) \cdot \sum (\hat{y}_i - y_i) \quad (5)$$

A Bias value close to zero indicates that the model neither consistently over-predicts nor under-predicts sales; by construction, an OLS model fitted on the same data has an in-sample Bias of zero, so RMSE and Bias are most informative when the model is validated on held-out months (e.g. a later test year) rather than on the data used to fit it. Reporting RMSE and Bias alongside R^2 gives a fuller picture of model performance: R^2 shows how much of the month-to-month variation is explained, while RMSE and Bias show how large and how directionally consistent the resulting prediction errors are likely to be in practical stock-planning use.

III. RESULTS AND DISCUSSION

A. Rainfall and Sales Move Together

Sales and rainfall move together across the eight years studied. Every year, fertilizer sales rise sharply as the monsoon arrives, peak between May and July and fall back once rain reduces after September. This pattern repeats every year with only small changes, which suggests it comes from the planting calendar itself rather than from chance.

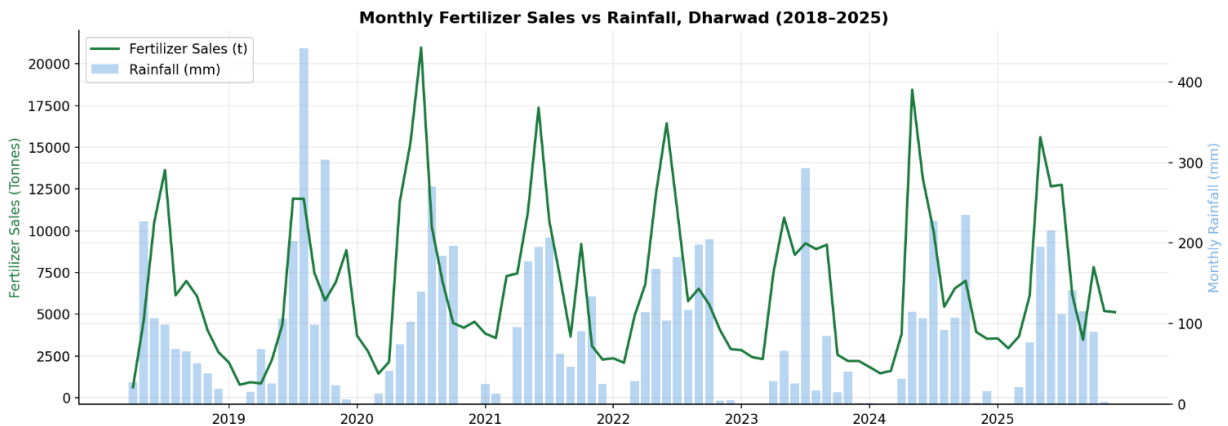


Fig. 1. Monthly fertilizer sales (line) plotted against monthly rainfall (bars), Dharwad, 2018-2025.

A simple linear regression, $Sales \approx 4,241 + 27.5 \times \text{Rainfall (mm)}$, is statistically significant ($p < 0.00001$). Rainfall alone explains close to thirty percent of the month-to-month change in sales ($R^2 = 0.30$).

This means rainfall is an important driver, but other factors also matter, since they explain the remaining seventy percent of the variation.

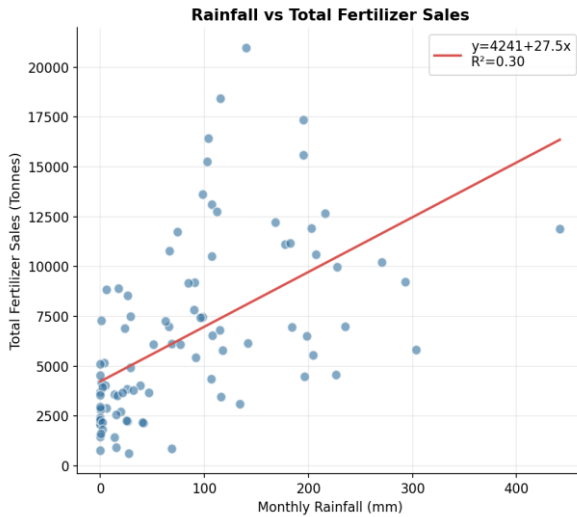


Fig. 2. Scatterplot of monthly rainfall against total fertilizer sales, with fitted regression line ($R^2 = 0.30$).

B. Product-wise Sensitivity to Rainfall

The strength of the rainfall-sales link is not the same for every product. Urea and NPKS show the strongest connection with rain, since they are applied as basal and top-dress doses once kharif sowing begins. DAP shows a moderate link, as it is often applied earlier in the season and is somewhat less tied to raintiming. MOP shows only a weak to moderate link. SSP stands out because its sales show almost no relationship with rainfall at all, which points to a separate group of buyers, possibly in horticulture or soil correction use, who do not plan purchases around the monsoon.

Table I lists both the Pearson and Spearman coefficients for each product. The Spearman value is higher than the Pearson value for most products, which means the rainfall-sales relationship is a little stronger when only the ranking of months is considered rather than the exact numbers. This is expected, since a small number of very wet or very dry months can pull a Pearson correlation away from the general pattern.

Overall, Urea and NPKS together explain most of the combined rainfall-sales correlation of 0.55, confirming that these two products should be treated as the core rain-linked items in any demand model built for this district.

The correlation matrix in Fig. 3 gives a wider view of how the products relate not only to rainfall but also to each other. Urea, DAP and NPKS are strongly correlated with one another and with total sales, which shows that they tend to move up and down together within the same purchasing months. This is expected, since farmers usually buy their full basket of nutrients together when preparing a field. SSP again stands apart, showing only weak correlation with the other products as well as with rainfall, which reinforces that it serves a different segment of buyers.

TABLE I. CORRELATION OF MONTHLY RAINFALL WITH PRODUCT SALES

Product	Pearson r	Spearman ρ	Remark
Urea	0.54	0.61	Strong
DAP	0.36	0.50	Moderate
MOP	0.22	0.43	Weak-moderate
NPKS	0.49	0.62	Strong
SSP	0.07	0.00	None
All products	0.55	0.66	Strong

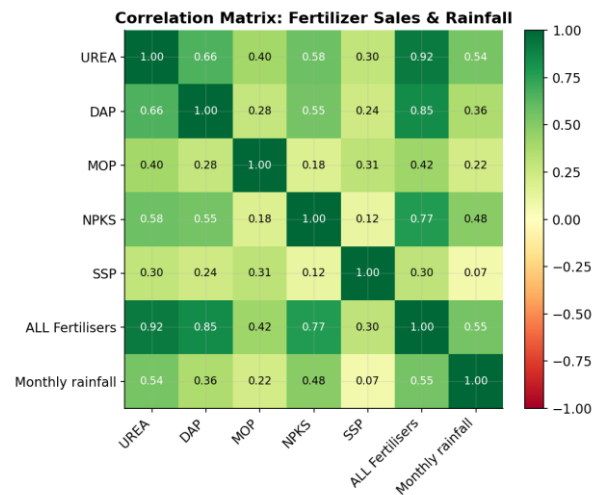


Fig. 3. Correlation matrix across all products and rainfall.

C. Seasonal Pattern: Kharif Carries the Market

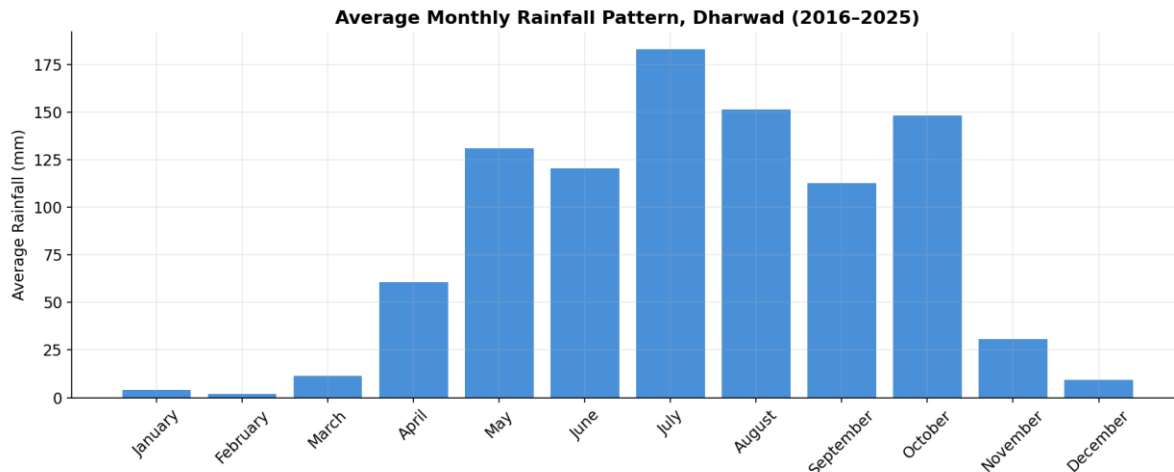


Fig. 4. Average monthly rainfall profile, Dharwad, showing the June-October monsoon window.

Grouping months by season confirms the same story at a broader level. Kharif months (June to October) see the highest average sales and the highest average rainfall. Summer months (April and May) see moderate sales tied to pre-monsoon sowing.

Rabi months (November to March) see both the lowest rainfall and the lowest sales. This matches earlier findings that Indian kharif output is directly tied to summer monsoon rain, while rabi output depends more on stored moisture from the previous season [6], [8].

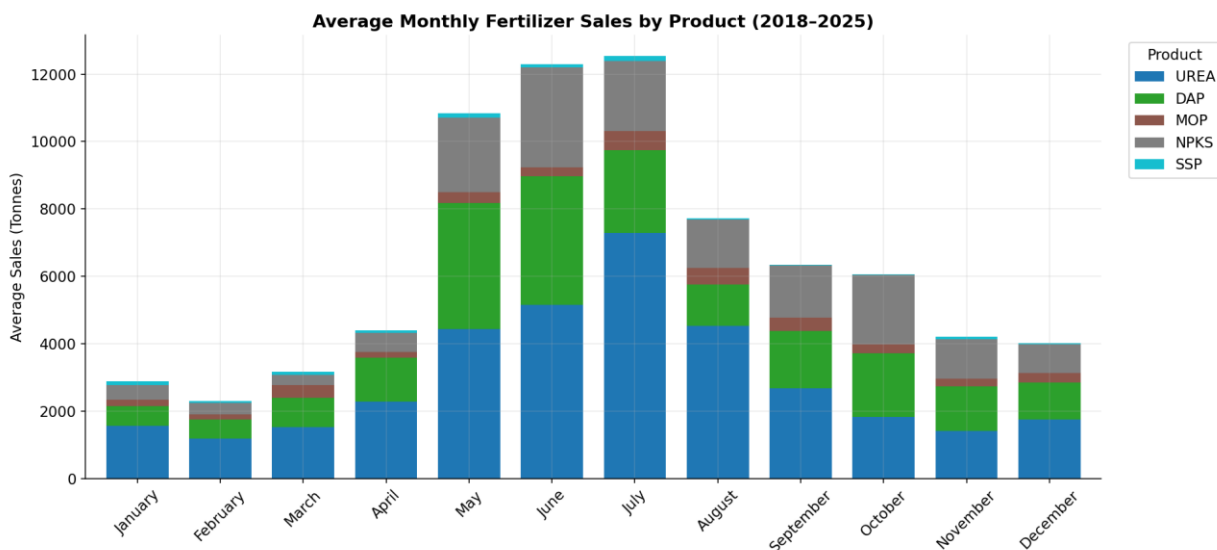


Fig. 5. Average monthly sales by product, stacked, showing the same June-September bulge as rainfall.

The kharif season alone accounts for close to fifty-nine percent of all fertilizer volume sold across the eight study years, even though it covers only five of the twelve months. This single fact is the clearest business takeaway from the seasonal analysis: dealers and manufacturers should treat the kharif window as the period that decides most of the year's total volume and should plan stock, logistics and staff around it well ahead of June.

TABLE II. AVERAGE MONTHLY SALES AND RAINFALL BY SEASON

Season	Avg. sales (t)	Avg. rainfall (mm)
Kharif (Jun-Oct)	8,993	143.1
Summer (Apr-May)	7,622	95.9
Rabi (Nov-Mar)	3,358	12.0

D. Dry Months Depress Demand Sharply

The clearest and most useful signal in the data is the dry-month effect. Thirteen months with zero recorded rainfall sold an average of only 2,787 tonnes, compared with 7,121 tonnes in the eighty months that had some rain. This gap is large and statistically strong (Welch's $t = -7.21$, $p < 0.0001$). Fig. 6 shows this difference as a box plot: the dry-month box sits much lower and is tighter, while the wet-month box is higher and spread over a wider range, showing that some rain, even a small amount, is enough to push sales toward much higher levels.

When months are split into four equal groups by rainfall amount (quartiles), the wettest group averages 9,607 tonnes sold against 3,379 tonnes in the driest group, close to a three-fold difference. A month with no rain at all is a clear early-warning sign that demand will fall sharply and this is more useful for planning than treating rainfall as a smooth, continuous driver. In practice, this means a dealer watching the weather bulletin does not need an exact rainfall forecast in mm; simply knowing whether rain is expected at all in the coming weeks already carries strong information about likely demand.

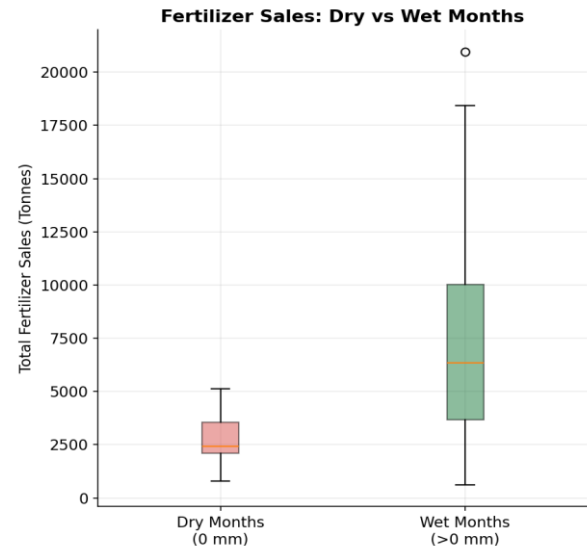


Fig. 6. Fertilizer sales distribution in completely dry months (0 mm) versus any-rainfall months.

E. One-Month Lag Effect

A one-month lag test checked whether last month's rain predicts this month's sales. A modest lag effect is present for the rain-sensitive products (Urea lag-1 $r = 0.34$, $p < 0.001$; NPKS lag-1 $r = 0.37$, $p < 0.001$), but it fades by the second month and is weaker than the same-month relationship. This suggests that farmers and dealers in Dharwad restock quickly once rain begins, rather than buying well ahead of the season.

This finding has a direct operational meaning: it is difficult to use last month's rainfall alone to build a stock plan for next month, since the same-month rainfall matters much more. Dealers would gain more from tracking rainfall as it happens and keeping a small buffer stock ready to move quickly once rain starts, rather than trying to forecast sales purely from the previous month's weather.

F. Year-on-Year Trend

Annual fertilizer sales rose from 55,313 tonnes in 2018 to a peak of 88,474 tonnes in 2020 and have since stayed in the 69,000 to 85,000 tonne range. The straight-line year-on-year growth trend (+2,449 tonnes per year) is not statistically significant ($p = 0.20$) given only eight years of data. The pattern looks more like a step-up around 2019-2020 followed by a plateau, rather than steady growth. Annual rainfall itself shows no clear trend and swings between about 574 mm in 2023 and 1,291 mm in 2019, which shows that year-to-year rainfall variability is itself a source of demand risk that dealers must plan for [13].

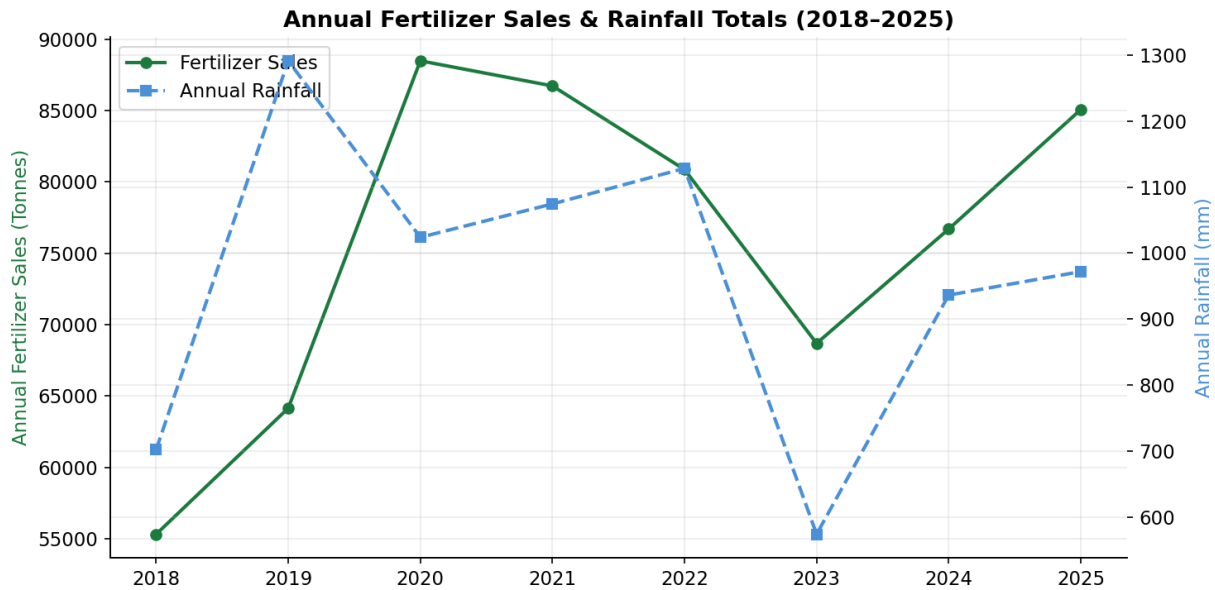


Fig. 7. Annual totals for fertilizer sales and rainfall, 2018-2025.

G. Product Mix

Urea leads the product mix with 46.3 percent of total sales volume, followed by DAP at 26.8 percent and NPKS at 21.0 percent. MOP (4.7 percent) and SSP (1.2 percent) are much smaller shares. When volatility is measured using the coefficient of variation, MOP (107 percent) and SSP (101 percent) swing far more relative to their own average than Urea (74 percent). The smaller product lines are therefore proportionally less predictable, even though they carry less absolute volume risk for the business.

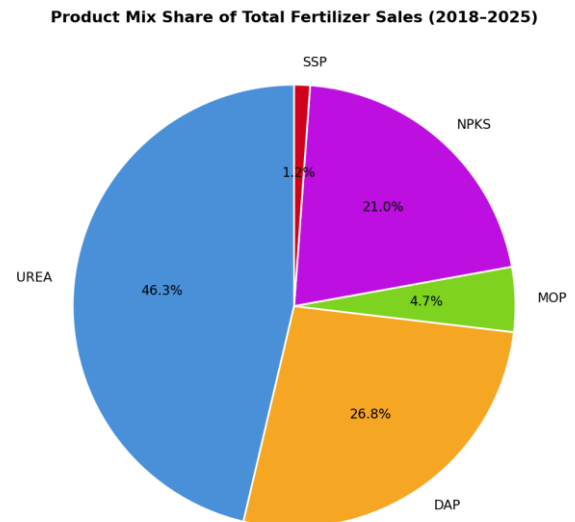


Fig. 8. Share of total sales volume by product, 2018-2025.

IV. PRACTICAL IMPLICATIONS

A. Implications for Agri-Input Dealers

Agri-input dealers can use the dry-month and quartile findings directly. Since the wettest quarter of months sells roughly three times more than the driest quarter, a dealer who tracks daily rainfall bulletins can adjust stock orders for Urea and NPKS ahead of the kharif window rather than reacting after demand has already surged [11], [14]. Because the lag effect is weak, pre-positioning stock a month in advance based on last month's rain alone is not reliable; it is safer to keep a flexible buffer that can be released quickly once rain is confirmed in the current month.

B. Implications for Policy and Supply Planning

For policy makers and input-supply planners, SSP's near-zero rainfall correlation is worth separate attention. This suggests a customer segment, possibly horticulture growers or farmers using SSP for soil correction, whose demand pattern does not follow the standard monsoon calendar. Understanding this segment separately could help in designing steadier, year-round supply and subsidy planning for that product, instead of applying the same monsoon-linked logistics used for Urea and NPKS.

C. Risk-Management Angle

From a risk-management view, the dry-month threshold is a simple and usable early-warning signal. Rather than only watching total seasonal rainfall, a business can flag any month with zero or near-zero rainfall as a likely low-demand month and adjust credit exposure and inventory carrying costs accordingly. This kind of threshold rule is easier for field staff to apply than a continuous statistical model, even though it is built on the same regression and correlation evidence.

D. The Headline Number

At a broader level, the single most quotable finding from this study is the roughly two-and-a-half-fold jump in average sales between completely dry months and any-rainfall months. This one number captures the core message of the paper: in Dharwad, the presence of rain, more than its exact amount, is what moves the fertilizer market.

V. LIMITATIONS AND FUTURE SCOPE

This study has some limitations that should be kept in mind while reading the results. First, the analysis covers only one district, Dharwad, so the exact figures may not directly apply to districts with different soil types, cropping patterns or irrigation coverage.

Second, only rainfall and time were used as explanatory factors; other known drivers of fertilizer demand, such as subsidy disbursement timing, dealer credit limits, crop prices and input costs, were not directly available in this dataset and could not be tested [3], [13]. Third, the linear regression model explains about thirty percent of the variation in sales, which means it should be read as evidence of a real relationship, not as a precise forecasting tool on its own.

Fourth, monthly totals were used instead of daily or weekly figures, so very short bursts of rain and their immediate effect on buying behaviour could not be captured. Future studies could add weekly PoS data, include subsidy and credit variables and extend the same method to other districts in Karnataka to check whether the dry-month threshold effect and the strong Urea and NPKS response to rainfall hold more generally across the region.

VI. CONCLUSION

Rainfall is a real and statistically significant driver of fertilizer demand in Dharwad, but it works mainly as a seasonal gate rather than a fine dial. The bigger story is kharif versus rabi, not small week-to-week changes in rainfall. The clearest actionable signal is the dry-month effect: sales in zero-rainfall months fall to roughly a third of wet-month levels and this can act as an early warning for inventory and credit planning. Urea and NPKS together form the rain-sensitive backbone of the business and should anchor any rainfall-based forecasting model, while SSP needs a separate demand driver since it does not respond to rain. A one-month lag effect exists but is weaker than the same-month link, showing that dealers restock quickly and reactively rather than well ahead of the season. Sales growth stepped up sharply in 2019-2020 and has since levelled off, so future growth is likely to depend more on monsoon reliability than on any background upward trend.

Taken together, these findings suggest that agri-input businesses in Dharwad should plan primarily around the cropping calendar, use dry-month signals as a short-term early warning and treat SSP as a distinct, less weather-driven line of business. Extending this method to more districts and adding non-rainfall variables would be a useful next step for building a fuller demand-forecasting model for the region.

In direct response to the research problem posed at the outset, this study finds that rainfall in Dharwad district functions less as a continuous predictor and more as a seasonal trigger: its clearest value lies in distinguishing dry months from any-rainfall months and in flagging the kharif window as the period that determines most of the year's fertilizer volume.



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This contributes to the wider literature on rainfall-input linkages [1], [6], [8] by providing, for the first time for Dharwad district, a transaction-level, product-wise quantification of that linkage using eight years of PoS data rather than aggregated annual figures. The regression, correlation and dry-month threshold results together offer a practical, low-data decision rule that agri-input dealers and district planners can apply using nothing more than a daily rainfall bulletin. Future research extending this model with RMSE- and Bias-based out-of-sample validation, additional demand drivers such as subsidy disbursal and dealer credit limits, and replication across other districts of the Karnataka dry zone would help establish how far these findings generalize beyond Dharwad.

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