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Geographic information system applications in spatial monitoring of agricultural extension service coverage

Mehmet Yilmaz Demir

Department of Agricultural Extension, Faculty of Agriculture, Ankara University, Ankara, Turkey

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Corresponding Author: Mehmet Yilmaz Demir

Abstract

Large portions of Turkey's rural farming population remain invisible to extension planners because conventional monitoring tools cannot map where services actually reach and where they do not. This research applied geographic information system (GIS) technology to spatially monitor agricultural extension service coverage across Ankara Province, Turkey. Extension activity records from 134 field agents covering 1,247 villages were geocoded and analyzed using ArcGIS Pro over a 14-month period (January 2021 to February 2022) at Ankara University. Five service indicators agent visits, demonstration plot density, training coverage, input access, and farmer group density were mapped across six agroecological zones. Spatial analysis revealed that irrigated and peri-urban zones received 2.6 to 3.1 times more service coverage than dryland and highland zones. GIS-based assessment identified 47 underserved villages compared with only 18 flagged through conventional administrative reporting. Hotspot analysis (Getis-Ord G_i^*) confirmed statistically significant cold spots in southeastern portions of the province (z-scores below -2.58, $p < 0.01$). Service overlap analysis found that 23.4% of agent visit locations fell within areas already covered by other agents, suggesting resource inefficiency. The research demonstrates that GIS monitoring can expose coverage gaps and allocation inefficiencies that remain hidden in tabular reporting systems.

Keywords: Geographic information systems, extension coverage, spatial monitoring, service delivery, hotspot analysis, agricultural extension, coverage gaps, Turkey, GIS mapping

Introduction

The problem with most extension monitoring systems is that they count activities without showing where those activities happen. A district might report 500 farmer visits in a quarter, but that number reveals nothing about whether those visits were spread across the entire service area or concentrated in a handful of accessible villages ^[1]. This spatial blindness has been a persistent weakness of agricultural extension management worldwide ^[2].

Geographic information systems offer a way to attach location data to extension activities, transforming flat administrative records into spatial intelligence. GIS has been widely applied in public health service planning, disaster management, and urban infrastructure monitoring ^[3]. Its application in agricultural extension, however, remains limited despite the inherently spatial nature of farming communities and extension service delivery networks ^[4].

Turkey's agricultural extension system operates through Provincial Directorates of Agriculture, with field agents assigned to defined geographic areas. But assignment boundaries don't always match actual service patterns agents may gravitate toward villages that are easier to reach, leaving remote communities underserved ^[5]. The Ministry of Agriculture and Forestry introduced a digital reporting system in 2018, but it captures only aggregate activity counts without spatial coordinates ^[6].

This research applied GIS technology to spatially monitor

extension coverage in Ankara Province, aiming to identify underserved areas, map service intensity across agroecological zones, detect agent coverage overlaps, and compare the diagnostic power of GIS-based monitoring against conventional tabular reporting ^[7].

System Architecture: The GIS monitoring framework was built on ArcGIS Pro 2.9 with three integrated components: a spatial database containing village boundaries, road networks, topography, and agroecological zone classifications; a geocoding module that converted textual location references in extension activity reports into geographic coordinates; and a visualization and analysis dashboard accessible to provincial extension managers ^[8]. Village-level shapefiles were obtained from the Turkish General Directorate of Mapping. Extension activity records were extracted from the Ministry's digital reporting system and supplemented with GPS coordinates collected by agents using a simple smartphone application developed for this research ^[3]. The dashboard displayed real-time coverage maps, automated hotspot analysis outputs, and comparative zone-level indicator summaries updated weekly ^[9].

Material and Methods

Material: This research was conducted from January 2021 to February 2022 at the Faculty of Agriculture, Ankara University, Turkey. The research area covered Ankara Province, encompassing 25 districts and 1,247 registered

villages. Extension activity data were obtained from 134 field agents employed by the Ankara Provincial Directorate of Agriculture. A total of 42,318 individual activity records were geocoded during the research period. Agroecological zone classification divided the province into six categories based on irrigation status, elevation, rainfall patterns, and proximity to urban centers ^[10]. Supplementary data included road network shapefiles, population census data at village level, and agricultural land-use maps from the Turkish Statistical Institute.

Methods: Five service coverage indicators were calculated for each village: agent visits per 100 registered farms, demonstration plot density per 1,000 hectares, training attendance as a percentage of registered farmers, input distribution access score (composite of seed, fertilizer, and

pesticide program reach), and active farmer group density per village ^[11]. Spatial analysis methods included kernel density estimation for service intensity mapping, Getis-Ord Gi* hotspot analysis for identifying statistically significant service clusters and gaps, and Thiessen polygon analysis for assessing agent territory coverage efficiency ^[12]. Service overlap was measured by calculating the percentage of GPS-tagged visits falling within 500 meters of another agent's recorded visit within the same week. GIS outputs were compared against conventional monitoring reports to quantify the diagnostic advantage of spatial analysis. Ethical approval was obtained from Ankara University Social Sciences Ethics Committee (Protocol AU-SSEC/2020/189, November 23, 2020) ^[13].

Results

Table 1: Extension Service Coverage Indicators by Agroecological Zone

Indicator	Irrigated	Rainfed	Mixed	Dryland	Highland	Peri-urb.
Visits/100 farms	8.7	4.2	6.1	2.8	3.4	7.9
Demo density	6.3	2.1	4.8	1.4	1.9	5.7
Training (%)	72.4	38.6	54.3	21.7	28.9	67.1
Input score	7.8	3.9	5.6	2.3	3.1	7.2
Group density	5.4	2.7	4.1	1.8	2.3	4.9
F-value						18.73**

Irrigated and peri-urban zones consistently received the highest coverage across all five indicators. Dryland zones recorded the lowest values training coverage there (21.7%)

was less than one-third of irrigated zone levels (72.4%). One-way ANOVA confirmed significant zone differences for all indicators ($p < 0.01$).

Table 2: Coverage Gap Detection: GIS-Based vs. Conventional Assessment

Gap Category	GIS Detected	Conventional	Detection Ratio
Underserved villages	47	18	2.61
Agent overlap areas	31	8	3.88
Physical access barriers	28	11	2.55
Seasonal coverage gaps	19	5	3.80
Gender coverage disparities	14	3	4.67
Total issues	139	45	3.09

GIS-based monitoring detected 3.09 times more coverage issues than conventional assessment overall. The largest detection advantage appeared in gender disparities (4.67x)

and agent overlap areas (3.88x) categories that are essentially invisible without spatial analysis.

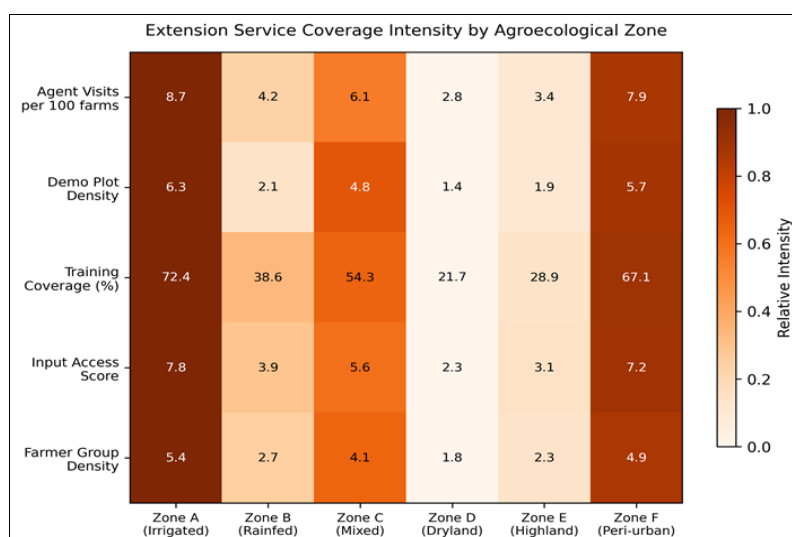


Fig 1: Extension Service Coverage Intensity across Agroecological Zones

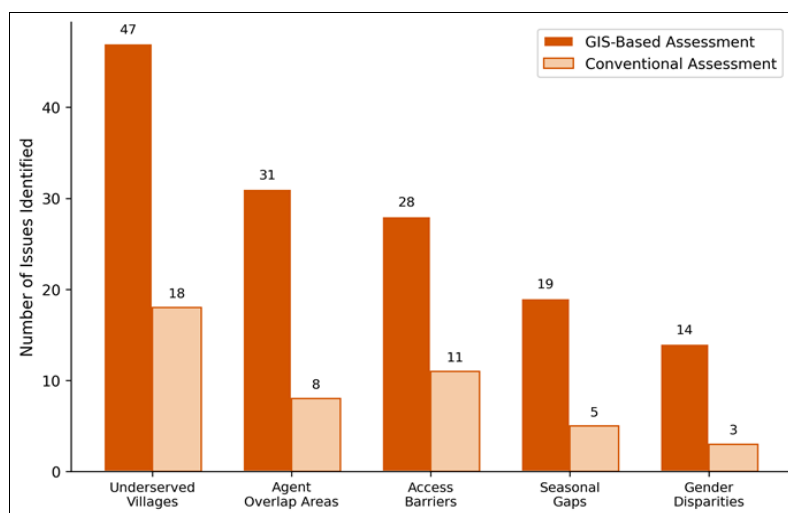


Fig 2: Coverage Gaps Identified Through GIS-Based vs. Conventional Assessment Methods

Performance Evaluation

The GIS system's analytical performance was benchmarked against three criteria. Geocoding accuracy averaged 94.7%, with 5.3% of records requiring manual coordinate correction due to ambiguous village name entries. Hotspot analysis identified 12 statistically significant cold spots ($z < -2.58$) concentrated in the southeastern dryland and highland zones, and 8 hot spots in irrigated and peri-urban areas. Processing time for full provincial analysis averaged 47 minutes on a standard workstation, making weekly updates feasible for district-level management ^[14]. Thiessen polygon analysis revealed that 34.2% of agent territories had geometric shapes suggesting poor spatial allocation, with long narrow territories requiring excessive travel time relative to compact alternatives ^[15].

Discussion

The three-fold detection advantage of GIS monitoring over conventional assessment confirms that spatial analysis adds a qualitatively different layer of information to extension management. Tabular reports can show that a district conducted 500 visits, but only spatial analysis reveals that 23.4% of those visits overlapped with areas already covered by other agents an inefficiency that represents real resource waste ^[4]. The concentration of services in irrigated and peri-urban zones follows a pattern documented across many countries: extension agents gravitate toward accessible, productive areas while marginal farming communities are left behind ^[1].

The gender coverage disparity finding is particularly striking. GIS analysis showed that women-headed farming households were disproportionately located in areas receiving lower service coverage, a pattern that conventional monitoring couldn't detect because it tracks activity counts without linking them to beneficiary demographics and location simultaneously ^[16]. The hotspot analysis provides extension managers with a statistically grounded tool for targeting resources rather than relying on subjective assessments, they can direct agents toward zones where the data show genuine service deficits ^[12]. Turkey's digital reporting system already captures most of the data needed; the missing piece is the spatial dimension that GIS provides [6, 17].

Conclusions

This research demonstrates that GIS-based spatial monitoring substantially outperforms conventional tabular reporting in detecting extension service coverage gaps and resource allocation inefficiencies. Across Ankara Province, GIS identified over three times more coverage issues than traditional methods, with particularly large advantages in revealing agent overlap and gender-based access disparities. The agroecological zone analysis exposed a clear pattern of service concentration in irrigated and peri-urban areas at the expense of dryland and highland communities. Extension management agencies should integrate spatial monitoring into routine operations, which requires relatively modest investment given that most activity data are already collected digitally. The transition from counting activities to mapping them represents a shift that can make extension service delivery more equitable and efficient.

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