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Geospatial Health
Geospatial Health 2026; 21:1455
doi:10.4081/gh.2026.1455

Unravelling the dual burden in regional context: how child malnutrition and socioeconomic gradients shape early childhood development

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Abstract

While the relationship between socioeconomic status and Early Childhood Development (ECD) is well-documented, less is known about how developmental outcomes and child malnutrition cluster and interact across geographically proximate areas. This study applies spatial analysis to examine regional disparities in ECD in Pakistan and to assess the extent of spatial dependency in these outcomes. Using cross-sectional data from multiple indicator cluster survey (120,151 children across 144 districts) covering 2017-2018, Moran's *I* statistics revealed significant positive spatial autocorrelation, consistent with Tobler's First Law of Geography. Districts with high (or low) ECD outcomes tended to be surrounded by similar districts. A distinct core periphery pattern emerged, with Punjab and Gilgit-Baltistan forming high-high clusters and Sindh, Khyber Pakhtunkhwa and Balochistan forming low-low clusters. Ordinary Least Squares (OLS) and Spatial Error Models (SEM) confirmed that stunting, underweight and overweight negatively affect ECD, while female literacy, access to mass media and child engagement in playing activities influence development positively. Wasting showed no significant relationship. Results reveal that unobserved regional factors contribute to child development across districts, indicating that developmental deficits often cluster geographically. These findings extend spatial dependency theory to the ECD context in South Asia, underscoring the need for geographically coordinated interventions that address both local determinants and regionally shared underlying influences on child development.

Key words: child malnutrition, early childhood development, spatial autocorrelation, spatial regression, coordinated interventions.

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Introduction

Early Childhood Development (ECD) is a multifaceted phenomenon capturing the developmental potential of children aged 3 to 5 years old across four key domains: literacy and numeracy, physical growth, socio-emotional well-being and learning. According to the United Nations (UN) these domains are fundamental for a child's future health and overall well-being (UN, 2019 do you mean: 2021). Contemporary estimates reveal that nearly 250 million children under five years of age (under 5) in developing countries are at risk of not reaching their maximum developmental potential (World Population Review, 2024 do you mean: 2022). In response, the UN has made ECD a priority under their Sustainable Development Goal (SDG) 4.2 aiming to ensure access to high quality early childhood services to children (Hák *et al.*, 2016). ECD can be attributed to multiple socioeconomic and external factors such as insufficient maternal nutrition, inadequate breastfeeding, excessive exposure to toxic pollutants, chronic malnutrition, poverty, physical and mental well-being of caregivers and abusive treatment. Balanced nutrition, particularly during the infancy period plays a crucial role in the progression of cognitive skills during the early years of child and beyond (Prado *et al.*, 2014). Malnutrition has long-term adverse repercussions on brain functionality. Lack of adequate nutrients is more likely to weaken brain development and will consequently result in long lasting cognitive disabilities. Additionally, nutritional deficiencies such as acute malnutrition, severe under-nutrition, iron and iodine deficiencies during early years can have a long lasting effect on a child's productivity throughout his school years and beyond (Atinc *et al*., 2013). For instance, a study in Nepal found a strong association between stunting and being underweight with a reduced likelihood of being developmentally on track for ECD, while no significant link was found with wasting (Shrestha *et al.*, 2022).

The global burden of child malnutrition is staggering, with approximately 140.9 million children under 5 affected by stunting and 49.5 million by wasting (Mannar *et al.*, 2020). South Asia alone is home to 82 million stunted children (UNICEF, 2020). Pakistan faces an overwhelming burden of child malnutrition. In 2022, the country reported a wasting rate of 17.7%, exceeding the emergency threshold, alongside a stunting rate of 40.2% and 28.9% of children being underweight (Government of Pakistan, 2022). This nutritional crisis is mirrored in the country's poor ECD outcomes. The World Bank estimates that only 40-55% of children in Pakistan aged 3-4 are developmentally on track, significantly below the 75% average for low- and middle-income countries (World Bank Group, 2022). This developmental lag is evident in foundational skills, with over a third of first-graders unable to read in English and over a quarter unable to read in their local language, while basic arithmetic proficiency has also declined. Pakistan's Human Capital Index (HCI) of 0.41 is well below the South Asian average of 0.49, highlighting an urgent need for effective interventions (Aser, 2021).

While the link between malnutrition and ECD is well-established, and the severity of this issue in Pakistan is undeniable, a critical research gap persists. Existing studies on ECD in Pakistan are limited in scope, focusing on specific risk factors like home environments and socioeconomic inequalities (Nadeem *et al.*, 2014; Khan *et al.*, 2018). Crucially, these studies are non-spatial, failing to account for regional variations and disparities in ECD. This oversight is significant because, as Waldo Tobler's First Law of Geography posits, "Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). Understanding the geographical distribution and clustering of ECD is essential for designing effective, location-specific policies. Regional inequalities are a global concern, addressed by SDG 10, which stresses the necessity of reducing inequality within and between countries (Usman & Kopczewska, 2022).

This study presents the first empirical attempt to investigate the spatial determinants of ECD in Pakistan. By leveraging spatial methods such as Moran's *I* statistic and a Spatial Error Model (SEM), we aimed to uncover the geographical disparities and identify spatial hotspots of poor ECD outcomes. This approach is novel and crucial by moving beyond national averages to provide actionable, region-specific insights. Findings of this study should have important implications for Pakistan as well as other South Asian countries battling with the double burden of ECD and child malnutrition.

Materials and Methods

Study area

Pakistan, a lower-middle-income country, is located between latitudes 23°35′ and 37°05′ North and longitudes 60°50′ and 77°50′ East. Administratively, it comprises four provinces: Punjab, Sindh, Khyber Pakhtunkhwa (KPK), and Balochistan, along with the Islamabad Capital Territory and the administrative regions of Gilgit-Baltistan and Azad Jammu and Kashmir. These areas are further subdivided into districts, totalling 144 across the country (World Population Review, 2022). Figure. 1 shows the geographical representation of the studied locations.

Data

The most recently available Multiple Indicators Cluster Survey (MICS) was used to extract data for all relevant variables. These surveys provide comprehensive information on various socio-economic, demographic, health, and housing indicators that offer valuable insights into ECD at the regional level in Pakistan (Bureau of Statistics Punjab, Planning & Development Board, Government of the Punjab. Multiple Indicator Cluster Survey Punjab, 2017-18). The MICS employed a stratified, two-stage sampling approach. A total of 6,596 Enumeration Areas (EAs) were surveyed, encompassing 129,957 households and 120,151 children across all six regions of Pakistan. The data were collected using three separate questionnaires: one each for children; women; and households covering indicators related to demographics, socioeconomic status, health, environment and housing. Table 1 below summarises the region wise surveyed EAs, households and children.

Variables were coded following the standard MICS format of the United Nations Chidren's Fund (UNICEF), with detailed metadata and value labels for categorical responses. For this study, we extracted variables relevant to early childhood development and its determinants from the respective datasets: i) child-level variables (*e.g.*, age, sex, nutritional indicators, participation in play activities) from the children's questionnaire; ii) maternal and household characteristics (*e.g.*, female literacy, household size) from the women's and household questionnaires; and iii) district and provincial identifiers from the survey's geographic metadata. Data cleaning involved re-coding categorical variables into binary or continuous measures where appropriate. Missing or implausible values *(e.g.*, height-for-age z-scores outside the ±6 SD range) were treated following UNICEF's MICS guidelines. Child-level and household-level datasets were merged using the household and cluster identifiers to ensure correct linkage. Since the analysis was conducted at the district level, all household and child-level variables were aggregated to district means or proportions, depending on the variable type. Continuous variables *(e.g.,* mean household size) were aggregated using the following formula:

$$Mean = 1/n \sum_{i=1}^{n} VARi \qquad \text{(Eq. 1)}$$

Binary and categorical indicators were aggregated as proportions (*e.g.*, percentage of children stunted, percentage of literate

Figure 1. Regional map of Pakistan.

Table 1. Number of Enumeration Areas (EAs), households and children.

	Punjab	KPK	AZD	Gilgit	Balochistan	Sindh	Total
EAs	2,692	1,127	398	323	1,029	1,027	6,596
Households	51,660	23,501	7,606	6,213	20,974	20,003	129,957
Children under 5	42,408	24,345	6,065	7,005	25,638	14,690	120,151

KPK, Khyber Pakhtunkhwa; AZD, Azad Kashmir.

mothers) by dividing the number of positive responses by the total number of valid responses within each district. The resulting district-level dataset contained one row per district with all selected indicators prepared for subsequent spatial and regression analyses. This study takes a regional perspective, using districts as the unit of analysis. Consequently, all relevant variables were aggregated at the district level for all districts of Pakistan. As dependent variable, we used ECD, which is multifaceted and encompasses an orderly growth of motor, cognitive, socio-emotional, language and regulatory skills during the first five years of life. A total of ten items were used to evaluate whether children are progressing developmentally across the four domains obtained from the MICS and designed in line with UNICEF's Early Childhood Development Index (ECDI) framework (Table 2).

These domains: literacy-numeracy, physical, social-emotional, and learning capture multidimensional aspects of child development. Each module comprises validated items designed to reflect age-appropriate developmental milestones. For instance, the literacy-numeracy domain assesses the ability to identify letters, read simple words and recognise numbers; the physical domain measures gross and fine motor skills; the social-emotional domain evaluates behaviour regulation and social interaction; and the learning domain reflects attentiveness and readiness to learn.

ECD is then calculated as a percentage of children who are developmentally on track in at least three of the four domains mentioned above. This cut-off is used in international monitoring because it captures children who demonstrate well-rounded developmental readiness, while accounting for normal variation in one domain. Validation studies indicate that the three-domain threshold balances sensitivity (identifying most children who are developmentally ready) and specificity (excluding those with multiple developmental delays), and provides consistent estimates across diverse cultural settings (UNICEF, 2023). The existing literature provides a wide range of explanatory features that are related with early childhood development. Independent variables were classified into three broad domains- household and socioeconomic, child learning and responsive care and child malnutrition measures. Household and socioeconomic includes household mean size, multidimensional poverty, female literacy and women exposure to mass media. Child learning and responsive care are shown to promote learning in children. It includes children playing activities: toys and books and children engagement with fathers and mothers. Health related measures entail child anthropometric measures: stunting, wasting, overweight and underweight.

Analysis

We started with explanatory spatial data analysis to inspect regional distribution of ECD and to identify potential geographical disparities in ECD. To perform the analysis, we calculated Moran's *I* statistic as:

$$I = \frac{n}{\sum_i \sum_j \omega_{ij}} \frac{\sum_i \sum_j \omega_{ij}(z_i - z)(z_j - z)}{\sum_i (z_i - z)^2} \quad \text{(Eq. 2)}$$

where ω_{ij} signifies the spatial weights matrix (a row-standardised contiguity matrix that determines the extent of the spatial relationship among neighbouring locations based on proximity); Z_i and Zj represent the real observations at locations i and j, respectively; and n the total number of regions in the study area. Each entry was assigned a value of 1 if locations i and j are next to each other, indicating a spatial interaction between them, and a value of 0 if not adjacent.

Moran's *I* statistic determines the strength of spatial association among the regions, Its value lies between -1 to +1. A positive value demonstrates positive spatial dependence, suggesting that similar values of the observed variable tend to formulate spatial clusters, *i.e.* similar values are likely to be found in neighbouring districts suggesting that child development is positively agglomerated in space. Alternatively, a negative value depicts negative spatial autocorrelation, implying that districts with dissimilar values are located next to each other, while values close to 0 mean indicates random distribution (Anselin, 1995). Univariate Local Moran's *I* maps and Moran's scatter plots were employed to identify and investigate spatial clusters and outliers within the dataset. Specifically, these maps helped to detect hotspots, coldspots and outliers (districts with high values surrounded by low-value neighbours, or vice versa) (Getis & Ord, 1992). Furthermore, to investigate whether Moran's I value is statistically significant, a null hypothesis (Ho) of spatial dispersion was tested against an alternative hypothesis (H1) indicating the existence of spatial dependence.

Keith Ord has proposed a SEM which includes spatial dependence in the residuals (Ord, 1975), a framework that enables us to account for unobserved spatially related factors that may influence ECD outcomes across districts. The general form is as follows:

$$Y = XB + u, \quad u = \lambda W u + \varepsilon \quad \text{(Eq. 3)}$$

where Y is the response variable (an N×1 vector representing the

Table 2. ECD domains and modules.

No	Domain	Module
1 (a)	Literacy	Children are able to state at least 10 letters of the alphabet.
		Children recognize at least 4 simple alphabets.
		Children recognizing the symbols of alphabetic letters.
1 (b)	Numeracy	Children are able to state at least 10 letters of the numeric digits.
		Children are able to read at least 4 simple numeric digits.
		Children are able to identify the symbols of numeric digits.
2	Socio-emotional	Children who interact well with other children.
		Children who do not fight with other children and do not get distracted easily.
3	Physical	Children who can grasp a small and simple object with two fingers.
4	Learning	Children who can follow simple instructions on how to do a task correctly.

ECDI for each of the N district); X a N×k set of explanatory variables capturing socioeconomic, parental and nutritional determinants of child development*; β a k×1 vector that contains the beta coefficients associated with these covariates; λ the estimated spatial error coefficient; u an N×1 vector of spatially autocorrelated disturbances that is part of the SEM specification; W the spatial weights matrix; and ε an N×1 vector of independently distributed errors. SEM was chosen among the different spatial regression models. It is particularly suited for situations where spatial dependence arises from unobserved or omitted variables that are spatially correlated and captured through the error term (Anselin, 2005). This is conceptually consistent with our study context, where unmeasured regional characteristics (*e.g.*, policy implementation quality, localized infrastructure) may affect child development outcomes indirectly. SEM corrects for spatial dependence in the residuals, thereby producing consistent and efficient parameter estimates while still capturing global relationships between the variables of interest. Additionally, we used Akaike's information criterion (AIC) to select the best performing model among OLS and SEM (Burnham & Anderson, 2004).

These include the mean household size (MHZ), the multidimensional poverty index (MPIi), which reflect household economic status, asset ownership, and multidimensional deprivation, the female literacy rate (FEMLITi) as a proxy for maternal education, and the women's exposure to mass media (WMNEXPi) such as television, mobile etc. Parental engagement is captured by father's (FATHENGi) and mother's (MOTHENi) involvement in learning activities along with a composite measure of parental interaction activities (PACTi) that reflects the frequency of stimulating behaviours, such as reading, storytelling, and playing. Nutritional determinants include stunting (STUNi), underweight (UNDRi), overweight (OVERi) and wasting (WASi) prevalence, as defined by World Health Organization (WHO) growth standards.

The SEM equation specified above can be utilized for the current study as:

$$ECDi = \beta_0 + \beta 1MHZi + \beta 2MDPIi + \beta 3FEMLITi + \beta 4WMNEXPi + \beta 5FATHENGi + \beta 6MOTHEN + \beta 7PACTi + \beta 8STUNi + \beta 9WASi + \beta 10UNDRi + \beta 11OVERi + \rho W + ei \quad \text{(Eq. 4)}$$

Given the well-established link between socioeconomic conditions and children's nutritional status, we incorporated multiple socioeconomic indicators into the model to account for this correlation and reduce potential confounding bias. Specifically, the Multidimensional Poverty Index (MDPI), female literacy rate, mean household size, and other relevant socioeconomic measures were included alongside malnutrition indicators. This specification allowed us to estimate the independent association between malnutrition and early childhood development while controlling for the broader socioeconomic context. Prior to model estimation, correlation matrix and Variance Inflation Factor (VIFs) were computed to assess multicollinearity between malnutrition and socioeconomic variables, with all values remaining below the conventional threshold of 10, indicating that no serious multicollinearity problem was present. We also applied classical Ordinary Least Squares (OLS) that provides a baseline for assessing the global (spatially invariant) relationship between the dependent and explanatory variables (Lesage *et al.*, 2023). However, OLS assumes spatial independence of residuals, and violation of this assumption can lead to inefficient and potentially biased estimates (Elhorst, 2014). To evaluate this assumption, Moran's I statistic was computed on the OLS residuals. A statistically significant Moran's I indicated spatial autocorrelation in the residuals, implying that unobserved factors influencing ECD may be spatially clustered. This justified moving beyond OLS to a spatial regression framework (Moran, 1950).

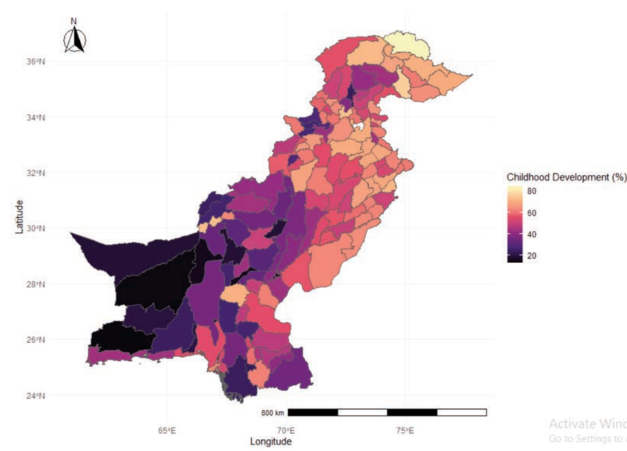


Figure 2. Spatial distribution of early childhood development values.

Table 3. Descriptive statistics.

Variable	Mean (%)	SD	Minimum (%)	Maximum (%)
Early childhood development (ECD)	49.1	16.83	13.1	84.1
Mean household size	7.58	2.41	3.9	19.0
Women's literacy	38.48	22.87	2.0	84.7
Women's exposure to mass media	31.12	30.63	0.1	86.6
Multidimensional poverty	40.98	21.35	2.0	87.8
Stunting	40.3	14.9	10.1	78.6
Underweight	27.4	14.6	3.3	75.5
Wasting	10.4	8.3	0.3	57.1
Overweight	4.50	6.12	0.1	51.8
Father's engagement	5.44	8.60	0.1	52.2
Mother's engagement	14.62	16.32	0.3	86.5
Playing activities	55.09	15.11	7.7	87.0

Multicollinearity testing

Before assessing the influence of independent variables on ECD, it is essential to evaluate whether the selected features exhibit multicollinearity-an issue where variables are highly related with each other. Multicollinearity can undermine the reliability and efficiency of regression results leading to biased and inefficient estimates. To assess this risk, we computed the correlation matrix between the independent variables.

In addition, VIF values were also computed to examine potential multicollinearity among predictors prior model fitting. According to the rule of thumb, a VIF value exceeding 10 indicates multicollinearity.

Results

Geographical distribution of ECD

Figure 2 illustrates the significant regional variation in ECD rates across Pakistan. It can be categorised into five quantiles: very low (ECD <20), low (20 ≤ ECD < 40), moderate (40 ≤ ECD < 60), high (60 ≤ ECD < 80) and very high (ECD ≥ 80). In Punjab, nearly all districts were found to exhibit moderate to high ECD rates and a similar trend observed in the districts of Gilgit. In contrast, the upper central regions of Balochistan predominantly reported very low to low ECD rates, underscoring substantial regional disparities. Sindh and Khyber Pakhtunkhwa (KPK) demonstrated a mixed pattern, with rates ranging from very low and low to moderate levels. Washuk District in Balochistan recorded the lowest ECD rate at 13.1%, while Hunza District in Gilgit reported the highest rate at 84%. This sharp contrast highlights the considerable heterogeneity across various regions of the country**.**

The descriptive statistics presented in Table 3 show the scale of problems as well as its regional diversification among the regions of Pakistan. Approximately, only half of the children in Pakistan were developmentally on track with an average value of 49.1%. The average stunting rate was 40.3%, regionally ranging from 10.1% to 78.6%. The average value for underweight was 27.4% with a minimum value of 3.3% and a maximum value of 75.5%. The mean household size was on average 7.58 and multidimensional poverty stood at 40.98%. Fathers and mothers engagement with their children showed disappointing numbers with an average value of 5.44% and 14.62%. Additionally, on an average approximately half of the children (55%) were engaged in learning and extracurricular activities such as book reading, story-telling and singing. Nearly, 38.9% of survey women were literate and merely 31.9% of them had exposure to mass media. The following statistics clearly illustrate that the country is in rather struggling circumstances.

Global and local spatial ECD dependence

Figure 3 illustrates Moran's *I* findings aggregated at the district level from the analysis. The Global Moran's *I* value was 0.43 (p<0.001), indicating a strong positive association among contiguous districts in Pakistan. This value suggests that 43% of neighbouring districts exhibit spatial clustering, either at the High-High (HH) or Low-Low (LL) level. Consequently, it is essential to identify these clusters at the district level.

Figure 3b shows the districts based on Local Moran's *I* classified into four clusters: HH, LL, High-Low (HL), and Low-High (LH). A significant concentration of HH districts followed by a notable presence of LL ones is evident. The former were primarily found in the regions of Punjab, Kashmir and Gilgit-Baltistan, while the latter were predominantly located in Sindh, Balochistan and KPK. Interestingly, both the HH and LL clusters were seen to be accompanied by HL and LH spatial outliers. This indicates that a few districts within the entire study area exhibited a, and another few showed the opposite result: a low ECD value surrounded by districts with high ECD values.

The map excludes Islamabad Capital Territory (white region).

Multicollinearity results

The pair-wise correlation matrix between the independent variables is shown in Figure 4. All coefficients lie within acceptable limits, with none exceeding the commonly used threshold for multicollinearity (|r|≥0.7). This confirms that the predictors do not exhibit problematic multicollinearity.

All variables had VIF scores below 7, suggesting the absence of significant multicollinearity among the explanatory variables. This result indicates that each predictor provides unique information about ECD, supporting the reliability of our regression analysis.

Regression results

The OLS and SEM model results are summarized in Table 4, with several notable findings. Both models tend to yield comparable results except for stunting and women's exposure to mass media. Specifically, OLS model estimates suggest that a 1 percentage point (p.p.) increase in women literacy may translate to a 0.21 p.p increase in ECD and the magnitude of this relationship is 0.16 in SEM. Similarly, children's involvement in playing activities increases the ECD by 0.29 p.p. as per the OLS results, however

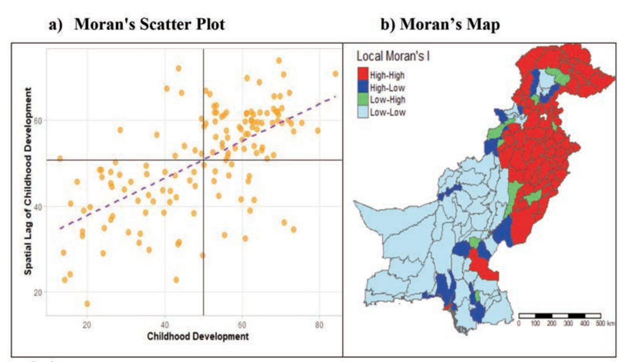
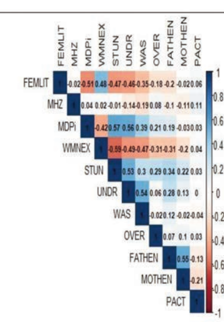


Figure 3. Aggregations at the district level with Global Moran's *I* findings compared to Local Moran's *I*.



Variable	VIF value
Multidimensional poverty	1.251
Mean household size	2.007
Women's literacy	1.289
Women's exposure to mass media	2.385
Stunting	1.754
Underweight	1.689
Wasting	3.987
Overweight	2.931
Father's engagement	1.378
Mother's engagement	2.347
Playing activities	1.386

VIF=Variance Inflation Factor

Figure 4. Pair-wise correlation matrix between the independent variables.

this drops to 0.21 p.p. in the SEM estimates. Comparable findings were revealed by both OLS and SEM results for underweight and overweight. Both child malnutrition measures have a negative impact on ECD. Furthermore, OLS results suggest that stunting and wasting both are insignificant. However, SEM estimates illustrate that ECD was reduced by 0.22 p.p. with a 1 p.p. increase in stunting. No significant relationship was found for multidimensional poverty, father's and mother's engagement with ECD.

Model diagnostics indicate that SEM outperformed OLS with a lower AIC value (SEM_{AIC} = 1,129 < OLS_{AIC} = 1,140). The estimated spatial error coefficient λ is 0.63 and is statistically significant which indicates moderate to strong spatial dependence in error terms strongly significant. It further justifies the need to use SEM to account for unobserved spatial processes.

Discussion

The study fills a significant void in the current literature by providing a comprehensive spatial analysis that can guide targeted and timely interventions, rather than one-size-fits-all policies. By revealing how ECD and its determinants, particularly malnutrition, vary across Pakistan's diverse regions, this research has important policy implications not only for Pakistan but also for other South Asian countries facing a similar double burden of ECD challenges and child malnutrition. Concerning ECD in Pakistan, our study highlights that nearly 50% of children aged 36-59 months are not developmentally on track, which is considerably higher than the regional average of 39% reported for South Asia (Chi *et al.*, 2025). This gap signals an urgent need for interventions targeted to the country's most disadvantaged regions.

Significant regional disparities in ECD were observed across all the regions of Pakistan, findings that underscore the marked inequalities in ECD outcomes, particularly highlighting the more pronounced disparities in Balochistan compared to other regions. The outlier clusters found reveal spatial dependence patterns, indicating that children's developmental outcomes are not randomly distributed but influenced by regional socioeconomic and infrastructural factors. Recognising these statistically significant clusters provides actionable insights for policymakers to prioritise resource allocation in contiguous underperforming areas rather than treating each district in isolation.

Our results indicate a negative association between stunting, overweight, and underweight status and Early Childhood Development (ECD), findings that align with existing literature that consistently links child nutritional outcomes to ECD. For instance, a recent study in Nepal examined the impact of malnutrition on ECD, revealing that stunting and underweight status were associated with lower odds of being developmentally on track (Mccoy *et al.*, 2016). However, we found a more substantial negative impact of underweight (β ≈ –0.48 OLS; β ≈ –0.47 SEM; $p<0.05$) on ECD in comparison to that found in Nepal highlighting extreme vulnerability in Pakistan.

Similarly, a meta-analysis focusing on South Asian countries found that both stunting and underweight were linked to poorer learning and developmental achievements in children. Interestingly, we observed no significant impact of wasting on ECD. This finding aligns with the inconsistent results found in existing studies on the wasting-ECD association. A study in Bangladesh showed that children experiencing wasting performed worse in motor development compared to non-wasted peers. Conversely, a panel study across South Asian countries reported no significant association between wasting and ECD (Kang *et al.*, 2018) These mixed results underscore the need for further research to clarify the relationship between wasting and ECD.

After controlling for other variables, maternal education was found to have a positive association with ECD. In the early years, a child's development is significantly influenced by their mother, and educated mothers often possess enhanced communication and learning skills that positively impact a child's growth and development. This finding aligns with existing research on the relationship between maternal education and ECD (Nahar *et al.*, 2020). Further research suggests that, despite the presence of child malnutrition, home environmental factors particularly care-giving and child interaction play a crucial role in promoting early cognitive development (Hasan *et al.*, 2023). Surprisingly, neither father nor mother engagement reached statistical significance, diverging from other studies reported in the literature on the significant effect of parental engagement on early childhood development (Chi *et al.*, 2025). Together, these findings underscore the importance of

Table 4. Estimated results from regression modelling.

Explanatory variable	OLS (SD)	SEM (SD)
Multidimensional poverty	-0.07(0.10)	-0.04(0.09)
Mean household size	-0.09(0.43)	-0.22(0.36)
Women's literacy	0.21(0.08)*	0.16(0.07)**
Women's exposure to mass media	0.11(0.05)*	0.03(0.48)
Stunting	0.18(0.15)	-0.22(0.13)*
Underweight	-0.48(0.18)**	-0.47(0.16)**
Wasting	0.29(0.22)	0.31(0.19)
Overweight	-0.35(0.18)*	-0.30(0.17)*
Father's engagement	0.17(0.18)	0.05(0.17)
Mother's engagement	0.13(0.10)	0.08(0.09)
Playing activities	0.29(0.07)**	0.20(0.06)**
Spatial coefficient λ		0.63*
Model diagnostics		
Adjusted R^2	0.42	0.56
AIC	1140	1129

*OLS, ordinary least squares; spatial error model; SD, standard error; ***p<0.001; **p<0.01; *p<0.05; p<0.1.*

maternal education and the role of play in fostering ECD, while highlighting potential gaps in parental engagement that could influence child development.

In LL clusters such as combining female literacy initiatives, nutrition-sensitive cash transfers, and community-driven play and learning programs could yield amplified outcomes. However, nutrition schemes would be more effective if integrated with parental education and structured play-based learning, simultaneously tackling nutritional deficits and cognitive gaps as reported by Kirkwood *et al.* (2023). Given the high coefficients for play activities both in OLS and SEM models, formalizing play-based curricula within health and community outreach systems could offer disproportionately high developmental returns in Pakistan's context (Daelmans *et al.*, 2017). Importantly, the negative association of overweight with ECD performance, an often overlooked issue in South Asian policy, suggests that nutrition strategies should address not only under-nutrition but also diet quality and early-life obesity prevention to ensure holistic child development.

Limitations

While this study benefits from a relatively large sample size, its geographical scope is limited to Pakistan. As such, the findings may not be directly generalizable to other countries or regions with different socioeconomic structures, cultural contexts and policy environments. The spatial patterns and relationships identified here are shaped by Pakistan's unique demographic distribution, governance structure, and environmental challenges, which may not hold in the same form elsewhere. Nevertheless, the methodological framework adopted in this study combining OLS and spatial regression techniques can be readily applied to other contexts, allowing researchers to test whether similar spatial dependencies and relationships exist in different settings. Future research could extend this analysis to a multi-country or cross-regional study, enabling a more comprehensive assessment of the factors influencing early childhood development across varying socioecological environments.

Conclusions

This study demonstrates that child malnutrition is a strong predictor of ECD among children aged 36–59 months. The results also revealed significant regional disparities in ECD outcomes, reflecting unequal access to quality health care, early learning opportunities, and differences in policy implementation and socio-cultural contexts. Addressing these inequalities requires region-specific strategies tailored to the unique challenges of disadvantaged areas. Moreover, the positive association between female literacy and ECD highlights the critical role of maternal education in promoting responsive care-giving and creating supportive home environments. Overall, the findings suggest that nutrition-focused programs alone are inadequate. A comprehensive, multi-sectoral approach integrating nutritional support with early stimulation, play-based learning, and initiatives that enhance female education is essential to ensure children reach their full developmental potential and to promote equitable progress in early childhood development.

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Received: 16 October 2025; Accepted: 18 December 2025.

Funding: not applicable.

Conflicts of interest: not applicable.

Data availability statement: all data were collected from publicly open repositories.