INTERNATIONAL JOURNAL OF
STUDIES IN SOCIAL SCIENCES AND HUMANITIES
IJOSSH, Vol 2(2) 2025
DOI: https://doi.org/10.25047/ijossh.v2i2.6722

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Politeknik Negeri Jember, Indonesia

Mapping Adolescents Vulnerable to Early Marriage Using K-Means Clustering: Strategies for Nutrition Prevention

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Abstract

Early marriage remains a critical public health concern with significant implications for adolescent reproductive health, nutrition, and socio-economic well-being. Adolescents who marry before reaching maturity face higher risks of malnutrition, anemia, and obstetric complications, while their children are more likely to experience low birth weight, stunting, and delayed development. Beyond health effects, early marriage limits educational attainment and employment opportunities, reinforcing intergenerational cycles of poverty. In Jember Regency, early marriage contributes to elevated Maternal Mortality Rate (MMR) and Infant Mortality Rate (IMR), emphasizing the need for evidence-based prevention efforts. This study aimed to classify adolescents' vulnerability to early marriage using the K-Means Clustering algorithm. A total of 30 adolescents aged 15–18 years from Karangpring Village, Sukorambi District, participated. Most respondents were 16 years old (53%), female (87%), and of Javanese ethnicity (90%). Data collected included demographics, as well as knowledge, attitudes, behaviors, and intentions related to early marriage. K-Means analysis generated three clusters: high-risk (30%), defined by limited knowledge, permissive attitudes, supportive behaviors, and strong intentions to marry early; moderate-risk (47%), showing average knowledge, mixed attitudes and behaviors, and situational intentions; and low-risk (23%), marked by better knowledge, rejecting attitudes toward early marriage, education-supportive behaviors, and minimal intentions. These findings show that cluster analysis offers a systematic approach to identifying adolescent vulnerability profiles. Such evidence is essential for guiding targeted, context-specific interventions to reduce early marriage and mitigate its health and social consequences.

Keywords: *Early marriage, Adolescents, Nutritional problems, K-Means Clustering*

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1. Introduction

Child marriage, defined as marital unions occurring before the age of 18, remains a critical public health issue worldwide with profound consequences for adolescent health, education, and socio-economic development (UNICEF, 2023). Globally, more than 640 million women and girls alive today were married in childhood, and each year approximately 12 million additional girls enter marriage before reaching adulthood. Although prevalence has declined from 23% to about 19% in the past decade, progress remains too slow to meet the Sustainable Development Goal (SDG) target of eliminating child marriage by 2030. Early marriage is strongly associated with adolescent pregnancy: annually, 21 million girls aged 15–19 become pregnant, with 12 million giving birth, often within the context of marriage (WHO, 2023). These pregnancies pose high risks of anemia, obstetric complications, and maternal mortality for adolescents, while their children face increased risks of low birth weight, stunting, and early mortality.

In Indonesia, early marriage remains a pressing public health and social challenge. According to Marriage Law No. 16 of 2019, the minimum legal age for marriage is set at 19 years for both men and women, revising the previous provision that allowed marriage at 16 years for women. This legal reform aims to promote gender equality, protect adolescent health, and reduce the long-term impacts of early and child marriage (Government of the Republic of Indonesia, 2019). Marriages conducted below this threshold, with or without judicial dispensation, are categorized as early marriage in the Indonesian legal context. Despite these regulations, socio-cultural norms continue to normalize early marriage, particularly in rural and agrarian communities. Nationally, one in nine Indonesian women aged 20–24 was married before age 18 (UNICEF, 2023), with higher prevalence in provinces with entrenched cultural practices.

The prevalence of early marriage In Sukorambi District reached 56% in 2024, largely influenced by cultural norms among Madurese families. Parents often encourage early marriage to reduce economic burdens or preserve family honor, while undervaluing girls' education. These practices have direct implications for maternal and child health. Based on interviews with health officers at the community health center (*Puskesmas*), 15.5% of pregnant adolescents were reported to experience chronic energy deficiency and 30.9% suffered from anemia. Among children under five, 18.2% were underweight, 8.7% stunted, and 9.8% wasted, highlighting the strong link between early marriage, adolescent reproductive health, and nutritional outcomes.

Despite the magnitude of this problem, most existing interventions in Indonesia focus on generalized awareness-raising and educational campaigns. Such approaches often overlook the heterogeneity of adolescents' vulnerability to early marriage, which is shaped by diverse knowledge levels, attitudes, behaviors, and social pressures. This limitation creates a research gap: there has been little effort to

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systematically classify adolescents based on their risk of early marriage. The present study employs K-Means clustering to categorize adolescents in Karangpring Village, Jember Regency, according to their vulnerability to early marriage. This analytical approach provides empirical insights to guide targeted and context specific interventions that promote adolescent health and reduce the prevalence of early marriage in Indonesia. Unlike previous studies that primarily describe determinants or prevalence of early marriage using descriptive or regression analyses, this study introduces a clustering-based approach to classify adolescents according to their vulnerability levels (Smith, Brown, & Lee, 2019). This methodological innovation enables a more nuanced understanding of adolescent heterogeneity, integrating cognitive, attitudinal, and behavioral dimensions into a single analytical framework. Hence, this research contributes both methodologically and practically by providing a data-driven foundation for developing precision-based interventions and informing local policy decisions related to early marriage prevention.

2. Literature review

2.1. Early Marriage as a Global Health Issue

Early marriage, defined as unions before the age of 18, is a global phenomenon with significant health, social, and economic implications (UNICEF,2023). Worldwide, more than 640 million women and girls were married in childhood, and about 12 million additional girls marry before adulthood each year. Despite declines in prevalence, the reduction is too slow to achieve the Sustainable Development Goal (SDG) of eliminating child marriage by 2030. Early marriage is strongly associated with adolescent pregnancy, which is linked to higher risks of maternal mortality, anemia, obstetric complications, and adverse neonatal outcomes (WHO, 2023). In Indonesia, early marriage is defined legally by the Marriage Law No. 16 of 2019, which sets the minimum marriage age at 19 years for both men and women. Marriages below this age, whether with or without court dispensation, are considered early marriages. This legal provision is consistent with international standards that categorize marriage under 18 as child marriage, though practices often diverge due to cultural norms.

Indonesia continues to record high rates of early marriage. According to a UNICEF report, one in nine Indonesian women aged 20–24 was married before the age of 18 (UNICEF, 2023). Prevalence is highest in rural and agrarian communities, where economic pressures and cultural traditions often encourage early unions. At the local level, Sukorambi District in Jember Regency, East Java, provides a clear example. Based on official marriage records from 2024, there were 288 marriages registered in the district, with an additional 87 recorded separately. Among

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these cases, 42 brides were younger than 16 years old, and 242 brides were aged 16–17 years, whereas grooms were generally older, mostly 18 years or above. Education data reinforce this vulnerability: of the 288 cases, 49 brides had only primary education, 65 junior secondary, and 146 senior secondary education**,** with very few continuing to higher education. These figures demonstrate that early marriage in Sukorambi remains concentrated among adolescent girls with limited educational attainment, deeply embedded in cultural norms that continue to normalize early unions. Early marriage has significant consequences for adolescent girls and their children. Adolescent mothers are more likely to experience anemia, chronic energy deficiency, and complications during childbirth (Rah et al., 2020). Their children face greater risks of low birth weight, stunting, and undernutrition. Local data from Sukorambi Public Health Center illustrate this: 15.5% of pregnant adolescents experienced chronic energy deficiency, 30.9% were anemic, and among children under five, 18.2% were underweight, 8.7% stunted, and 9.8% wasted. These findings highlight the intergenerational effects of early marriage on maternal and child nutrition.

3. Method

This study employed a quantitative descriptive design using K-Means clustering to classify adolescents' vulnerability to early marriage. The research method directly addressed the identified gap, namely the absence of data-driven classifications that capture heterogeneity in adolescents' risk profiles. Traditional descriptive approaches have been insufficient in distinguishing nuanced subgroups; therefore, an unsupervised machine-learning method was selected to generate empirically derived clusters without predefined assumptions. Data were collected from 30 adolescents aged 15–19 years in Karangpring Village, Sukorambi District, through a structured questionnaire encompassing knowledge, attitudes, behaviors, and intentions related to early marriage domains highlighted in the literature as key predictors yet rarely analyzed in combination. The participants represented the target population lacking systematic vulnerability mapping, strengthening the relevance of the chosen method. All variables were normalized to a 0–1 scale prior to analysis. K-Means clustering was then applied, with the optimal number of clusters determined using the Elbow and Silhouette Coefficient methods. This process ensured methodological rigor and alignment with the objective of identifying distinct vulnerability groups. The resulting three clusters low, medium, and high risk, were further supported by Principal

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Component Analysis (PCA) visualization, as illustrated in Figure 1, which enhanced interpretability and confirmed cluster separation.

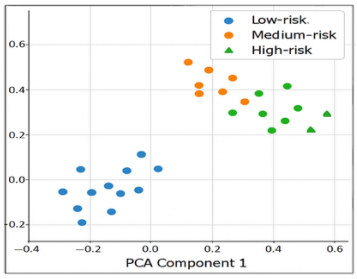

Figure 1. *PCA Scatter Plot of Adolescent Vulnerability Clusters to Early Marriage*

4. Findings and discussion

4.1.Characteristics of Respondents

The study was conducted among thirty adolescents aged 15–19 years residing in Karangpring Village, Sukorambi District, Jember Regency. The majority of respondents were female, consistent with the broader evidence that adolescent girls are disproportionately vulnerable to early marriage compared to their male counterparts. Most participants were aged 16–17 years, representing the critical age range at which early marriage is most prevalent. This distribution closely mirrors official marriage records from Sukorambi District in 2024, which documented 288 marriages, including 42 brides younger than 16 years and 242 brides aged 16–17 years. These records confirm that the age composition of the study sample reflects the population segment most at risk of early marriage within the local context, thereby strengthening the relevance of the findings.

4.2 Findings from Clustering Analysis

Application of the K-Means clustering method produced three distinct vulnerability groups among the adolescents.

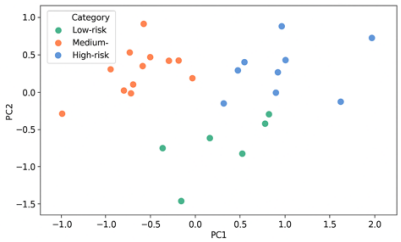

Figure 2. *Distribution of respondents based on k-means clustering (PCA 2D)*

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The two-dimensional PCA visualization illustrates the distribution of respondents according to their clustering results. Each point represents an adolescent, positioned based on the similarity of responses across knowledge, attitudes, behaviors, and intentions. The colors indicate the assigned clusters: green for the low-risk group, orange for the medium-risk group, and blue for the high-risk group. The figure demonstrates a clear separation among groups. Respondents in the medium-risk cluster dominate the sample and are concentrated in the central region, reflecting their ambivalent positions. In contrast, the low-risk cluster appears in the lower-left quadrant, while the high-risk cluster is concentrated in the upper-right quadrant, signifying sharper distinctions in their attitudes, behaviors, and intentions toward early marriage. Although some overlap exists, the overall pattern supports the validity of the clustering analysis (Figure 1).

This visual representation strengthens the numerical findings that knowledge levels were relatively homogeneous across clusters, whereas attitudes, behaviors, and particularly intentions were decisive in differentiating vulnerability. The separation illustrated in Figure 1 aligns with the Theory of Planned Behavior (Ajzen, 1991), which emphasizes intention as the most immediate predictor of behavior. It also reflects findings from Noer, Utami, and Kurniawan (2022) and Sekarayu and Nurwati (2021), who highlighted the influence of socio-cultural norms and ambivalence in shaping adolescents' decisions regarding early marriage.

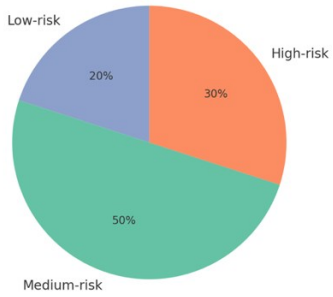

Figure 3. *Distribution of adolescents by vulnerability cluster*

The pie chart illustrates the proportion of adolescents classified into each vulnerability cluster. Half of the respondents (50%) were categorized as medium-risk, indicating ambivalence in attitudes and unstable intentions toward early marriage. A further 30% were identified as high-risk, characterized by permissive orientations and stronger acceptance of early marriage, while only 20% belonged to the low-risk cluster, demonstrating protective knowledge, attitudes, and behaviors. This distribution reveals that the majority of adolescents remain vulnerable, with only a small proportion exhibiting strong resilience, underscoring the need for targeted interventions (Figure 2).

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***Table 1**. Knowledge, attitude, and behavior scores of adolescents by vulnerability cluster*

Cluster	Knowledge	Attitude	Behavior
Low	0.43	1.07	0.31
Medium	0.35	0.83	0.37
High	0.41	1.21	0.72

Source: Primary data, 2024.

Table 1 indicates that knowledge levels were relatively similar across clusters, ranging from 0.35 to 0.43. This finding suggests that knowledge alone does not differentiate vulnerability to early marriage. Even adolescents in the high-risk cluster reported comparable knowledge scores to those in the low-risk cluster. This pattern is consistent with the findings of Noer, Utami, and Kurniawan (2022), who found that increased knowledge regarding the risks of early marriage does not necessarily result in behavioral change when strong cultural norms are present. Attitudes, however, showed greater variation across clusters. Adolescents in the low-risk cluster demonstrated strongly protective attitudes (1.07), while those in the high-risk cluster expressed more permissive attitudes (1.21). Attitude differences appear to be a more decisive factor in shaping vulnerability. This supports the Theory of Planned Behavior (Ajzen, 1991), which highlights attitudes as a key determinant of intention and subsequent behavior. It also aligns with the findings of Noer, Utami, and Kurniawan (2022), who emphasized that adolescents with permissive attitudes are more likely to follow cultural expectations for early marriage, regardless of their knowledge levels.

Behavioral patterns further reinforced the divergence among clusters. Adolescents in the low-risk group demonstrated protective behaviors (0.31), such as prioritizing education and delaying marriage, whereas those in the high-risk group exhibited permissive behaviors (0.72), reflecting readiness to conform to prevailing social norms. The medium-risk cluster displayed inconsistent behaviors (0.37), indicating uncertainty and transitional tendencies. This finding is consistent with Rah et al. (2020), who emphasized that behavioral inconsistency often mediates the relationship between knowledge and health outcomes, thereby increasing vulnerability to practices such as early marriage. Overall, these results suggest that although knowledge is evenly distributed across clusters, variations in attitudes and behaviors are key determinants of vulnerability. Consequently, interventions must move beyond information dissemination and focus on shaping behavioral and socio-cultural dimensions. The following section further elaborates this distinction by examining intention, the most decisive factor in differentiating vulnerability levels among adolescents.

***Table 2**. Intention scores of adolescents by vulnerability cluster*

Cluster	Intention
Low	1.00
Medium	1.29
High	1.49

Source: Primary data, 2024.

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As illustrated in Table 2, intention emerged as the most distinct differentiator of adolescent vulnerability. Adolescents in the low-risk cluster exhibited the lowest intention score (1.00), reflecting a consistent rejection of early marriage. In contrast, the medium-risk cluster recorded a higher score (1.29), indicating ambivalence and instability. Adolescents within this group did not fully support early marriage but remained susceptible to external influences, particularly parental authority and community norms. The high-risk cluster reported the highest intention (1.49), signaling strong acceptance or even preference for early marriage, despite having knowledge levels comparable to the low-risk group. This finding underscores the central role of intention in determining adolescent vulnerability. In line with the Theory of Planned Behavior (Ajzen,1991), intention represents the most immediate antecedent of behavior, mediating the relationship between attitudes and actions.

The results of this study reinforce that theoretical perspective, illustrating how intention can outweigh knowledge in shaping adolescents' predispositions toward early marriage. Consistent with Fitriah et al. (2025)**,** adolescents with strong intentions are more likely to proceed with early marriage regardless of risk awareness. Likewise, Sekarayu and Nurwati (2021) emphasized that intention frequently mirrors cultural acceptance rather than rational evaluation, particularly in communities where early marriage is normalized and socially reinforced. The overall analysis demonstrates that while knowledge scores were relatively uniform across clusters, attitudes, behaviors, and intentions were the key variables differentiating levels of vulnerability among adolescents. The low-risk cluster reflects a resilient group with consistently protective orientations, the medium-risk cluster represents adolescents in a state of ambivalence and heightened susceptibility, and the high-risk cluster encompasses those who, despite adequate awareness, remain permissive due to entrenched socio-cultural influences. The alignment of these clustering results with official marriage records from Sukorambi District (2024) further validates the analysis. Both primary and secondary data indicate that the majority of adolescents in the region remain highly vulnerable to early marriage, largely as a result of limited educational attainment and persistent cultural norms.

These findings are consistent with prior studies indicating that knowledge alone is insufficient to deter early marriage when social and familial pressures remain dominant (Noer, Utami, & Kurniawan, 2022; Sekarayu & Nurwati, 2021). A recent study by Khan et al. (2024) also highlighted that perceptions of early marriage timing are closely linked with educational and employment opportunities, emphasizing the broader socio-economic implications of adolescent marriage. A study in Aceh Province by Idawati (2024) revealed that women from the poorest households were 2.23 times more likely to marry early, highlighting the strong effects of parental influence and economic hardship. In Indonesia, studies have shown that higher educational attainment reduces the likelihood of early marriage (Fitria et al., 2024). A systematic review conducted by Subramanee et al. (2022) identified low education, rural residence, and economic deprivation as consistent risk factors, reinforcing that structural drivers often override individual knowledge**.** Consistently, *Fitriah et al. (2025)* reported that social and familial

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support strengthens adolescents' ability to resist early marriage. The clustering results provide actionable insights for local policymakers and health authorities. Interventions should prioritize medium and high risk adolescents through culturally tailored counseling, school-based reproductive health education, and family engagement programs. Involving religious and community leaders could also strengthen normative shifts away from early marriage. These targeted strategies align with Indonesia's National Strategy for Stunting Reduction and the Sustainable Development Goals (SDG 3 and 5), reinforcing the public health significance of this research.

5. Conclusion

This study applied K-Means clustering to classify adolescents in Karangpring Village, Sukorambi District, based on their vulnerability to early marriage. Three clusters were identified: low-risk (20%), medium-risk (50%), and high-risk (30%). Knowledge levels were relatively uniform, but attitudes, behaviors, and intentions distinguished vulnerability levels. The results show that socio-cultural factors strongly influence adolescents' readiness or resistance toward early marriage. K-Means clustering proved effective for identifying priority groups, offering an evidence-based approach to guide interventions. Strengthening education and peer influence is essential for low-risk adolescents, while enhancing decision-making capacity is needed for medium-risk groups. High-risk adolescents require culturally sensitive interventions involving families and community leaders to prevent early marriage.

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