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**Original Research Article**

# Predictive Modelling and Community Health System Factors for Reducing Preventable Neonatal Deaths in Mashonaland West Province, Zimbabwe, 2020-2021

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**Abstract:** In 2020, an average of 6,700 newborn babies died every day globally within the first 28 days of life and majority of these deaths were preventable. Current evidence shows that a continuum of institutional and community health system initiatives will not only save the lives of neonates but also prevent disability. This study modelled the predictive effect of institutionalizing community health system on reducing neonatal deaths. The study used an embedded sequential mixed methods design (QUAN (qual)), utilizing a two-arm parallel groups cluster randomized controlled trial in Mashonaland West, Zimbabwe. The intervention group participated in modified women's and men's participatory learning and action groups and received community health initiatives focused on training village health workers in essential newborn care and strengthening community governance. The control group received standard Ministry of Health and Child Care initiatives. Data was collected through structured questionnaires and analyzed using SPSS, Stata, and machine learning techniques, with a significance level of $p < 0.05$. Results indicated that the timing of neonatal death ($\chi^2 = 973$, $p < 0.0001$), low birth weight less than 2,500g ($\chi^2 = 129.6$, $p < 0.0001$), and women's literacy ($\chi^2 = 99.63$, $p < 0.0001$) were significantly associated with neonatal deaths. Fully functional community governance structures were linked with a reduced likelihood of neonatal death (ARR = 0.327, 95% CI: 0.21-0.44) and Area Under the Curve (AUC) of 0.84. Predictive models achieved high accuracy rates, with random forest demonstrating exceptional results strengthening the argument that the community health system interventions influenced reducing neonatal deaths. In conclusion, prioritizing initiatives that enhance early antenatal care booking and strengthening community health systems can effectively reduce preventable neonatal deaths.

**Keywords:** Preventable neonatal deaths, community health system, Village Health Workers, community governance.



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# INTRODUCTION

Community health continued to evolve, and over the past few decades, evidence has increasingly shown that community-based interventions significantly enhance reproductive, maternal, neonatal, and child health (RMNCH) (Bhutta, 2005; Story *et al.,* 2017). Community health supports the core principles of primary health care (PHC) by promoting equitable access to health services within local environments, encouraging meaningful community participation, fostering multisectoral collaboration, and adapting healthcare solutions to meet local needs in a culturally acceptable and affordable manner (World Health Organizatin (WHO), 1978; WHO, 2014; Bang *et al.,* 2010; Frenk *et al.,* 2014). However, the community-based primary health care (CBPHC) approach, which could help reduce health inequities by providing interventions directly to households and communities, remains the weakest aspect of health systems in developing countries. This is particularly critical in regions where 97% of maternal, neonatal, and child deaths occur (Bhutta *et al.,* 2017).

The neonatal period, encompassing the first 28 days of life, represents a critical phase for a child's survival. During this time, infants are at the highest risk of mortality, with a global average of 18 deaths per 1,000 live births reported in 2017. Notably, 47% of deaths among children under five during this period were attributed to newborns (WHO, 2019). The leading causes of neonatal mortality worldwide include complications from pre-term birth (35%), intra-partum issues - primarily birth asphyxia (23%), and neonatal infections (15%), which together account for over 75.8% of total deaths (Kananura *et al.,* 2016). A closer examination reveals that pre-term birth and congenital disorders, along with intrapartum complications, are predominant causes of death in the early neonatal phase (Oza *et al.,* 2015). In contrast, infections such as neonatal sepsis, pneumonia, and meningitis are the primary causes in the late neonatal phase, with a significant portion of these fatalities being preventable.

Given this context, it is estimated that if current trends continue, approximately 27.8 million children globally will die within their first month of life. According to data from the UN Inter-Agency Group for Child Mortality Estimation (UN IGME, 2019), over 60 countries need to expedite their efforts to meet the Sustainable Development Goal (SDG) target by 2030, with Zimbabwe ranking 41st (WHO, 2019). Additionally, these countries are likely to fall short of meeting the SDG target for reducing neonatal mortality rates, including Zimbabwe (Sharrow *et al.,* 2022).

Community health has become increasingly important in Zimbabwe and other nations, serving as a vital component in achieving the Sustainable Development Goals (SDGs), particularly SDG 3, which focuses on universal health coverage (UHC). It also supports other goals, such as eradicating hunger, promoting quality education, ensuring gender equality, providing clean water and sanitation, fostering innovation and infrastructure, reducing inequalities, and building partnerships. Zimbabwe is committed to enhancing its PHC approach to meet these ambitious goals. The country is also focused on developing a robust community health system, which is considered essential for effective PHC. In 2020, Zimbabwe ratified its first national community health strategy and an essential package of health services for community levels. Community health services encompass initiatives delivered through outreach programs and the work of community health workers (CHWs).

Acknowledging the significance of community health and the need to tackle existing challenges, the country is implementing reforms to create a comprehensive community health system that integrates various departments, partners, and sectors at all levels of the health system, emphasizing the role of communities, households and families. These reforms aim to resolve issues such as the vertical and fragmented nature of initiatives, limited access to services, inadequate service quality, child-unfriendly social norms, and insufficient community engagement in leadership and accountability. The proposed changes will establish community levels as the foundational tier of the health sector, formally integrating them into the overall health system and enhancing service delivery by bringing healthcare closer to local populations.

The high neonatal death rates in Zimbabwe, particularly in rural areas, are alarming and need urgent attention to meet Sustainable Development Goal 3 targets. Current trends indicate that without significant changes, achieving equitable survival rates for children in Zimbabwe by 2030 is unlikely. Factors such as socio-cultural, environmental, and behavioral influences, along with healthcare quality issues, play a crucial role in neonatal morbidity and mortality (Haider *et al.,* 2000; Haines *et al.,* 2007). While maternal and neonatal health programs often emphasize improving emergency obstetric and neonatal care and increasing access to skilled birth attendants, this study sought to model the predictive effect of institutionalizing community health system on reducing neonatal deaths in the rural province of Mashonaland West, Zimbabwe. In this study, institutionalizing community health was defined as engaging communities as key stakeholders in the delivery of effective locally specific, collaborative, and innovative effective community focused health development strategies to strengthen the existing primary health care system.

# METHODS

**Research Design**

A pragmatist paradigm was adopted and employed an embedded sequential mixed methods

approach (quantitative and qualitative) [QUAN (qual)] utilizing a two – arm parallel group cluster randomized controlled trial design.

**Study Setting**

The study was conducted in Mashonaland West province, located in western part of Zimbabwe. This region was chosen due to its high neonatal mortality rates, which facilitated the recruitment of a sufficient sample size. The province features a diverse range of settlements, reflecting the broader demographics of the country, and is characterized by limited health facilities, often situated over 20 to 40 km apart, highlighting the need for enhanced community health programming. The province benefits from a supportive provincial health executive and a dedicated district health management team, both of which have operational plans for implementing the new national community health strategy creating a valuable learning environment. With an estimated population of 1,593,328, the region anticipated around 66,113 pregnancies and 63,734 deliveries, making it a critical area for community-based health interventions (Zimbabwe Statistics Agency, 2018).

**A cluster randomized controlled trial (cRCT)**

The trial took place in rural, urban and peri urban communities within Mashonaland West province. Clusters were established according to recognized geographical boundaries, specifically the health facilities (clinics or rural hospitals) that serve an estimated population of 10,000 people in the selected districts. A cluster design was selected for this study, as the unit of randomization was a group rather than individual participants, which aimed to reduce the risk of contamination (Gabida *et al.* 2015; Tripathy, *et al.* 2016).

**Trial Profile**

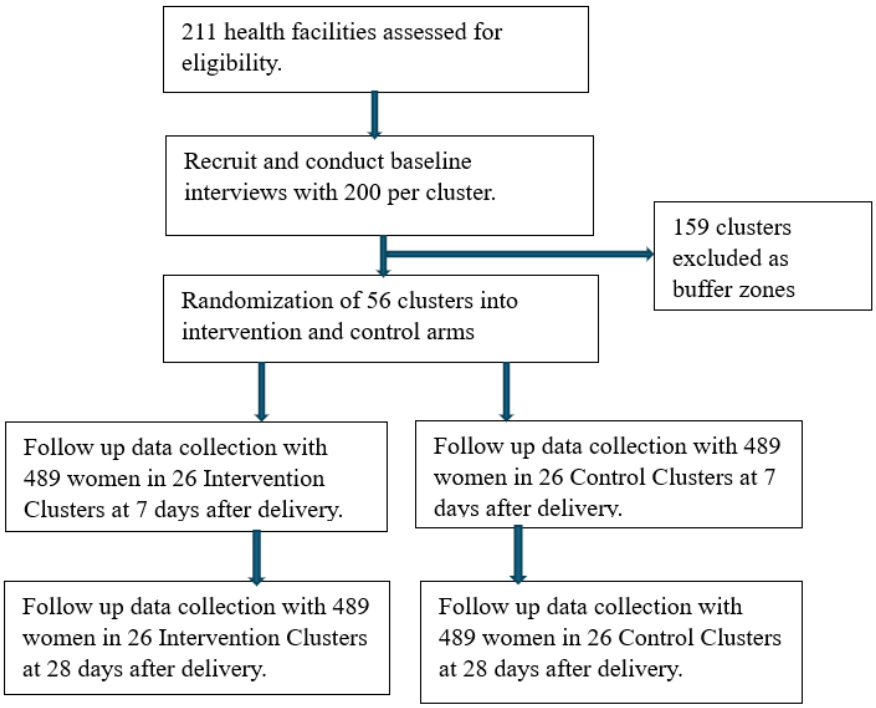


**Figure 1: Trial Profile**

**Intervention Protocol**

**Control group**

At the control sites, routine services were delivered in accordance with the national policies and protocols set by the Ministry of Health and Child Care (MOHCC) of Zimbabwe. Health workers are mandated to educate mothers during visits for maternal, newborn, and child health services, addressing issues like breastfeeding difficulties and arranging follow-ups as needed. Mothers were referred to community-based workers (village health workers) and received ongoing counseling throughout antenatal and postnatal care. VHWs, who undergo refresher training and supportive supervision from the MOHCC and its partners, are expected to conduct monthly home visits to every household in their communities, regardless of need.

This study coincided with the Government of Zimbabwe's phase 1 implementation of the National Community Health Strategy, which aimed to revitalize community governance structures such as Health Centre Committees (HCCs) and Village Health Committees (VHCs), recruit and train more VHWs, enhancing skills of existing VHWs, strengthen the Community Health Information System (CHIS), and streamline community health service delivery.

**Intervention Group**

At the intervention sites, mothers received routine services in line with the MOHCC national policy, including the National Community Health Strategy. The intervention employed a socio-ecological approach, utilizing the Tanahashi framework to enhance community health system coverage.

The study adapted a women's group intervention, traditionally focused on women, to include men (women's and men's learning and action group meetings) and the broader community in discussions about reproductive, maternal, neonatal, child health, and nutrition. This modification aimed to foster community accountability, recognizing the influence of various factors on child survival. The goal was to empower families and the entire community to address health issues affecting women and children, particularly in the context of Zimbabwe's patriarchal society.

The community-led intervention emphasized the community as the central agent of change. To facilitate this, a local VHW was trained for 92 hours to create networks of neighboring households, termed community health forums (CHFs). These forums aimed to promote active community participation through participatory learning and action meetings. Additionally, households received 24 hours of training on maternal, neonatal, and child health services as part of an essential health package, which included sessions on newborn care practices.

The VHWs effectively led networks of women and men in a series of community meetings focused on maternal and child health. They invited women of childbearing age to participate in five cycles of culturally tailored community mobilization sessions, drawing on successful models from countries like Bolivia, Nepal, Malawi, and Ethiopia.

In the first cycle, which lasted one month, women attended six meetings while men attended two, where they identified and prioritized health issues affecting women and children. They also discussed local solutions to these problems. The cycle concluded with a joint session for both women, men, young people of childbearing age. VHWs monitored progress and held monthly meetings with village health committees.

The second cycle, occurring in the second month, involved four meetings for women and one for men, during which community-led strategies were developed to address the identified health issues. Women shared these strategies with the entire village during a community assembly meeting.

In the third month, the third cycle included discussions with all community members to implement the strategies, while the fourth cycle focused on evaluating progress and planning for resilience. After completing all 15 sessions within three months, the VHWs facilitated a mapping and evaluation of practices concerning maternal, newborn, and child health in the village. Households that effectively implemented the agreed-upon actions discussed in community meetings were designated as change agents, responsible for influencing their neighbors. This approach fostered empowerment in community decision-making and encouraged ownership of health initiatives, leading to a rapid increase in positive health behaviors related to neonatal care, as families learned from one another. Key focus areas included early booking for antenatal care for pregnant women, institutional deliveries, recognition of danger signs for mothers and newborns, home care for newborns, and access to emergency transportation and care, when necessary, among others.

This initiative culminated into the fifth cycle of the community social accountability model. In this final phase, community-based audits were conducted to investigate the circumstances surrounding neonatal deaths. The objective of these audits was to pinpoint the underlying factors contributing to these fatalities, allowing for the development of targeted interventions to prevent future occurrences within the community. The fifth cycle was carried out during the fifth and sixth months.

**Cycles for women's and men's learning and action groups**

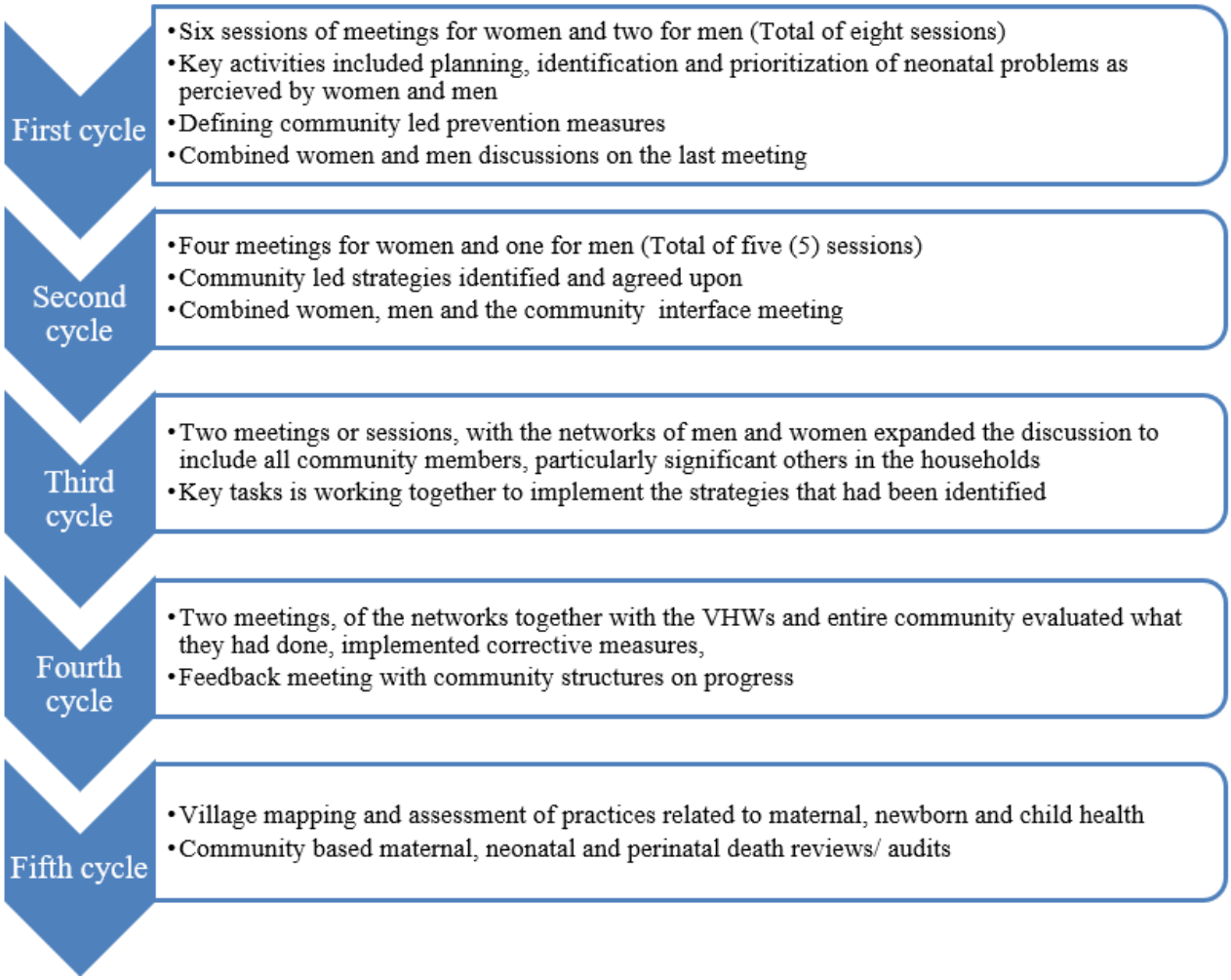


**Figure 2: Modified women's and men's learning and action groups on community led reduction in neonatal deaths**

The VHWs received ongoing on-the-job support from district health teams in accordance with MOHCC protocol, enabling them to help the CHFs utilize participatory rural appraisal tools and storytelling with picture cards, among other methods, to facilitate discussions and empower household networks to tap into their shared knowledge and skills. As they developed these capabilities, the groups gradually took greater control of the intervention throughout the cycles, relying solely on guidance from the VHWs, who were supported by trained peer supervisors and health facility teams that received quarterly assistance from the research team, without any direct resources from the research itself.

**Home based counselling**

The VHWs conducted two scheduled home visits during pregnancy and at least three postnatal visits within the first week after childbirth. These visits aimed to promote care-seeking throughout pregnancy, delivery, and the postpartum period. Emphasizing the World Health Organization's recommendation for eight antenatal care visits (adopted in Zimbabwe in 2018), VHWs focused on promoting early ANC booking, delivery in institutions, skilled birth attendance and essential newborn care practices such as household hygiene, clean cord care, skin-to-skin contact, kangaroo mother care (KMC), hypothermia prevention, early initiation and exclusive breastfeeding, and recognizing danger signs that require immediate medical attention. Additional support was provided for small and sick newborns, including two extra visits, guidance and support on KMC. Mothers received education on birth preparedness and the importance of maternity waiting homes to minimize delays in seeking care. All pregnancies, births, and deaths were documented by VHWs at community level.

In areas with an inadequate number of VHWs, the research team collaborated with the District Health Executive (DHE) to prioritize the recruitment and training of these workers, following the National Community Health Strategy 2020-2025. VHWs received ongoing supervision and accreditation as per the MOHCC guidelines, with training support from the MOHCC.

Finally, in partnership with the provincial health executive/team (PHE/PHT), the intervention aimed to institutionalize the community health system by integrating community health initiatives as a formal part of the health system as guided by the national community health strategy, revitalizing community structures, and establishing clear linkages with formal health system.

**Follow up**

Follow up of all eligible women was conducted by the research assistants within the first 28 days after birth. Day 3 was deferred because of the COVID restrictions. Any visits conducted after 28 days of baby's life was not included in this analysis.

**Study Endpoints and Outcomes**

The intervention was implemented over a one-year period. It was anticipated that the benefits of this intervention would become evident as early as six months post-implementation, as women are likely to be identified sooner in their pregnancies and receive appropriate follow-up care. The presence of VHWs in the same community as the pregnant women was expected to enhance the adoption of recommended practices and increase their exposure to the intervention.

**Target population and inclusion**

The research focused on women of childbearing age (15 and 49 years) old where mothers identified during pregnancy, were monitored until one month postpartum and who were permanent residents of the study cluster. Visitors from outside Mashonaland West, as well as individuals without informed written consent, were excluded from the study. According to the Multiple Cluster Indicator Survey (MICS) 2019, women of childbearing age represent 24.2% of the total population, which is an estimated 385,586 women in this age group was expected in the study area.

**Study Sample**

Given that this research incorporated both quantitative and qualitative elements, distinct procedures were employed for sampling and sample size determination to address each aspect effectively. For the quantitative component, the sample size was calculated using methods suited for cluster randomized controlled trials. A two-sided Z-test was utilized to assess the difference between proportions, with a statistical power of 80%, a significance level of 5%, a design effect of 1.0, and an estimated k value of 0.25, derived from studies conducted in Nepal and Bolivia. This approach aimed to detect a 24-33% reduction in preventable neonatal deaths following exposure to the intervention. The trial's primary objective was to evaluate the impact of institutionalizing the community health system on reducing preventable neonatal deaths. Consequently, the minimum sample size calculated for each arm was 489 pregnant women, resulting in a total of 978 mother-infant pairs recruited for final assessment across both arms (Bhutta *et al.* 2005; Lewycka *et al.* 2010; Lassi *et al.* 2010; Gabida *et al.* 2015).

For the qualitative aspect, sample size was not the primary focus, as the goal was to gain a comprehensive understanding of the information collected rather than to achieve statistical significance. However, saturation was ensured to adequately address the research questions (Joubert *et al.* 2007; Patton, 1990).

**Sampling and Data Collection**

Formative research involved enumerating all women of childbearing age in the study area from the 1st of February and 30th April 2020, where a total of 15,219 out of 87,916 households were visited. For participant selection during follow-up, stratified random sampling was utilized across the targeted districts in Mashonaland West province. Clusters were randomized and assigned to one of two groups using STATA version 14: 26 clusters received the intervention, while another 26 clusters received standard care only, in accordance with MOHCC policy. For the qualitative aspect, purposive sampling was used to recruit participants. Blinding participants to their group allocation was not feasible due to the nature of the intervention (Day and Altman, 2000). Nevertheless, data collectors remained unaware of the study details, and all analyses were conducted at the end of the study period.

Standard structured questionnaires, designed for individuals with low literacy, were developed based on prior studies from Southern Asia and sub-Saharan Africa. Feedback from research supervisors, health specialists, and a statistician were incorporated to enhance the tools, and an expert translator ensured the accuracy of the Shona translations. Pretesting was done in Mashonaland Central to ensure contextual relevance. Eligible women provided informed consent before participating in the study. Data collection was conducted by trained research assistants and supervisors. Additionally, qualitative data was gathered through focus group discussions, in-depth interviews, key informant interviews, with a minimum of 7 focus groups and 10 key informants per district, averaging 8 to 12 participants per group including observations. This approach aimed to also assess the quality of health care services provided.

**Data Analysis**

Quantitative data analysis involved cleaning, coding, and utilizing SPSS version 29 and Stata 14 for descriptive statistics to characterize the population and risk ratio (RR) analysis to identify crude associations with neonatal death. Conditional logistic regression calculated crude and adjusted risk ratios, with a stepwise approach for variable selection. Predictive modeling employed machine learning algorithms to identify significant predictors, prediction and feature importance. Multi-level logistic regression was done to estimate effects at different levels and model hierarchical effects,

integrating individual, household, and community factors, while also assessing the model's goodness of fit.

The multi-level model to estimate the cluster and province effects was as follows:

$\text{logit}\ (\pi_{ijk}) = \log(\pi_{ijk}\ 1-\pi_{ijk}) = \beta_0 + X_{ijk} + u_{0jk} + v_{0k}$ …… equation. (1)

where $\pi_{ij}$ denotes the probability that the $i^{th}$ neonate of $j^{th}$ cluster in the kth district/ province will die; $X_{ij}$ is a set of variables for each $i^{th}$ neonate of the $j^{th}$ cluster in the kth district/ province. The variables ($X_{ijk}$) represent a set of covariates pertinent to each neonate in that specific cluster and district. These covariates are categorized into individual-level, household-level, and community-level factors. $\beta_0$ was the associated vector of standard regression parameter estimates; $u_{0jk}$ represented the random effect at the cluster level; and v0k was the random effect at the district/ provincial level. The intercept of a neonatal death was assumed to vary randomly across clusters and provinces and the fixed effects were presented as risk ratios (RR) and the 95% confidence intervals (CI).

All analysis was by intention to treat at 5% statistical significance level and 95% confidence interval. Subgroup analysis differentiated between early and late neonatal deaths to understand timing and associated factors. Sensitivity analyses addressed missing data and potential variable interactions.

For qualitative data, interviews and focus group discussions were transcribed and analyzed using thematic content analysis. This involved coding, identifying recurrent themes, and summarizing perceptions and practices related to neonatal health. The analysis aimed to contextualize findings and inform community health programming, using tools like NVivo and Stata for comprehensive evaluation. The goal was to enhance understanding of neonatal mortality and improve health outcomes through targeted interventions.

**Ethical Approval**

Permission to conduct the study was granted by both the Research Ethics Committee of the University of Lusaka and the Medical Research Council of Zimbabwe (MRCZ). Prior to conducting the research, permission was obtained from the provincial and district health offices of the Ministry of Health and Child Care (MOHCC). All participating mothers provided informed written consent including consent for their minors. The study did not have any stopping rules, as no adverse effects were anticipated from participation. Nevertheless, participants were informed that they could withdraw from the study at any time without any consequences.

# RESULTS

**Baseline Information**

Between February 1 and April 30, 2020, a household census was carried out, during which 15,219 out of 87,916 households were visited. Participating households provided written informed consent to be included in the study and were interviewed to assess their baseline characteristics. This represented a total population of 60,876 individuals, of whom 15,828 were women of childbearing age (WCB) between 15 and 49 years old. Throughout the study, 21 women relocated from the study areas, and 113 passed away; however, none declined to participate. All interviewed households and women of childbearing age were considered eligible for the assessment of socio-economic status and demographic characteristics (Table 1).

**Table 1: Comparison of baseline population of women of childbearing age - 15-49 years enumerated; February - April 2020**

| Characteristic Description | Households | Total Population | Women of childbearing age | Proportion of WCBA |
|---|---|---|---|---|
| Total Target Population | 87,916 | 374,316 | 97,323 | 26% |
| Total enumerated | 15,219 | 60,876 | 15,828<br>15-24 years – 3,261<br>25-49 years – 12,567 | 16.3% |
| Interviewed during baseline | 10,718 | 45,016 | 11,705<br>15-24 years – 2,412<br>25-49 years – 9,293 | 12.1% |
| Refused | 0 | 0 | 0 | 0% |
| Died | - | - | 113 | 0.1% |
| Moved out of study area | | | 21 | |

**Household characteristics at baseline**

Baseline data on the interviewed women of childbearing age are presented in Table 3. Majority (73%) lived in rural areas, with approximately 7.6% residing in peri-urban communities. The median age of the women was 29 years, and 20.6% were adolescents aged 15 to 24. Most participants (63.1%) were married, with 16.9% in polygamous marriages, while 49.4% identified as non-conservative Christians. Notably, conservative religious groups, particularly from the Apostolic Sect, accounted for 31.1%.

**Table 2: Basic information of women of childbearing age**

| Basic information | Number (N = 11,705) | Percentage (%) |
|---|---|---|
| **Place of residence** | | |
| Rural | 8,545 | 73.0 |
| Urban | 2,299 | 19.4 |
| Peri-urban | 893 | 7.6 |
| **Age group** | | |
| 15 to 24 years | 2,412 | 20.6 |
| 25 to 49 years | 9,293 | 79.4 |
| **Marital Status** | | |
| Married | 7,392 | 63.1 |
| Never married | 2,575 | 22.1 |
| Divorced/ Separated | 1,066 | 9.1 |
| Widowed | 672 | 5.7 |
| **Polygamous marriage** | | |
| Yes | 1,979 | 16.9 |
| No | 9,726 | 83.1 |
| **Religion** | | |
| Conservative | 3,641 | 31.1 |
| Non-conservative | 5,783 | 49.4 |
| Traditionalist | 560 | 4.8 |
| Other | 1,721 | 14.7 |
| **Education level** | | |
| Primary | 2903 | 24.8 |
| Secondary | 7,574 | 64.7 |
| Tertiary | 1228 | 10.5 |
| **Employment status** | | |
| Formal employment | 726 | 6.2 |
| Self-employment | 1990 | 17.0 |
| Farmer | 4284 | 36.6 |
| Casual labor | 3137 | 26.8 |
| Panning | 1568 | 13.4 |
| **Pregnancy history** | | |
| Ever pregnant | 8,849 | 75.6 |
| Never pregnant | 2856 | 24.4 |
| **Current pregnancy** | | |
| Yes | 583 | 5.0 |
| No | 10,720 | 91.6 |
| Don't Know | 402 | 3.4 |
| **Average household size** | 4.3 | |

**Prospective trial enrolment of pregnant women**

The modified women's and men's participatory group intervention trial, conducted from September 1, 2020, to October 31, 2021, adhered to CONSORT guidelines (Figure 3). During this period, 984 pregnant women were recruited, with 277 (28.3%) being aged 15 to 24 years. The study included all live births, miscarriages, and stillbirths that occurred by October 30, 2021. Notably, all selected villages participated without refusal.

The trial recorded 973 total births, comprising 882 live births, 91 stillbirths, and 68 neonatal deaths, leading to a total of 159 perinatal deaths and 13 maternal deaths. Only 11 women (1.1%) were unable to participate in interviews due to requiring consent from their husbands, predominantly from control areas.

Among the neonatal deaths, 47 occurred within the first week (Early Neonatal Deaths) and 21 between 8 to 28 days (Late Neonatal Deaths). Verbal autopsies were performed to investigate the causes of neonatal deaths in both the intervention and control groups. However, five questionnaires were excluded due to respondents being unable to specify the timing of neonatal death, complicating the classification of these cases as stillbirths or live births (Figure 3).

**Demographic and socio-economic characteristics of pregnant women**

The comparisons of the demographic characteristics by intervention group allocation are described in Table 3, Table 4, and Table 5, using prospective data. There were no variations in characteristics of the mother such as median age,

education level, employment, marital status, parity and polygamy between the intervention and control group. A similar trend was also noted on the neonatal factors though a slight difference was noted on birth weight that seemed to be lower in control areas. There seems to be more of the non-conservative religious group but also a growing population of the other religious groups spread equally in the intervention and control groups. Overall, the intervention and control groups were comparable on baseline household factors, socioeconomic and demographic characteristics.

Most women resided in rural locations, with 70.7% in the modified women's and men's intervention group and 73.4% in the control areas. There was a notable presence of women residing in peri-urban areas, comprising 9.5% of the intervention group and 9.6% of the control group. Regarding socioeconomic status, the largest proportion of women of childbearing age belonged to the middle wealth quintile, representing 27.2% in the intervention group and 26.4% in the control group.

**Trial Profile**

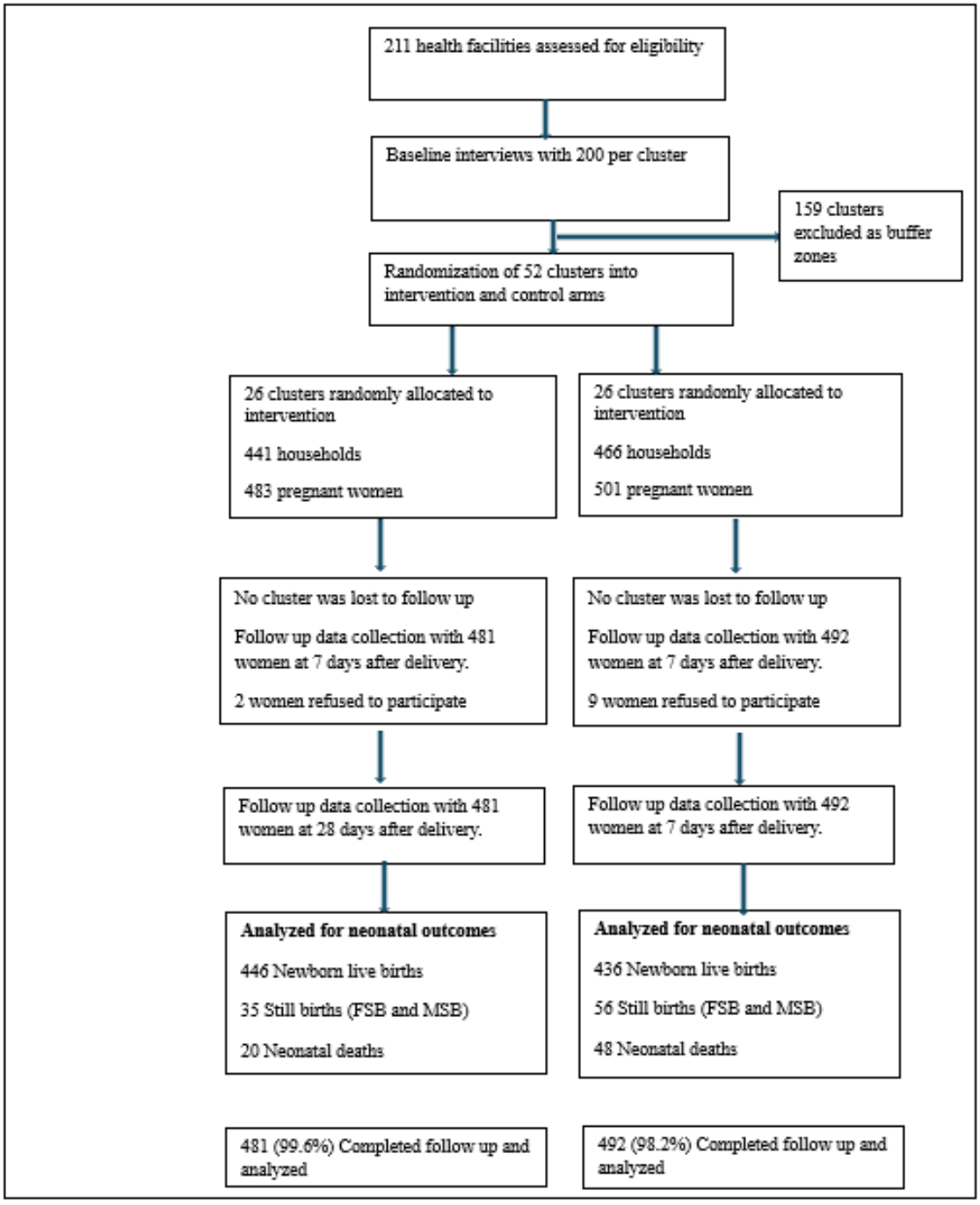


**Figure 3: Trial Profile: Randomization of study participants to intervention and control clusters**

Regarding community factors, 82.7% of women in the intervention areas indicated that community governance structures, specifically Health Centre Committees (HCCs) and Village Health Committees (VHCs), were fully operational, compared to only 34.3% of women in control areas. Concerning the presence of formal VHWs trained by the Ministry of Health and Child Care, 96% of women in the intervention areas reported having interacted with a VHW, compared to 73.4% in control areas. Additionally, 73.6% of women in the intervention group demonstrated moderate community literacy by being able to identify at least three newborn danger signs, compared to 62.4% in the control group (Table 3).

For maternal factors, the median age of mothers was 29 years, with the majority aged between 25 and 49 years (72.8% in the intervention group and 70.3% in the control group). Notably, younger mothers aged 15 to 24 years also formed a substantial proportion, accounting for nearly one-third of participants. Religious affiliation indicated that at least 45.3% of women in intervention areas belonged to non-conservative denominations compared to 44.3% in control areas. Conservative religious groups also represented a notable proportion, accounting for 34.1% in intervention areas and 37.4% in control areas (Table 4).

**Table 3: Household and community level characteristics by intervention allocation for women of childbearing age, 2020-2021 (n=973)**

| Variables | | Intervention (n=481) (%) | Control (n=492) (%) |
|---|---|---|---|
| **Household Characteristics** | | | |
| **Place of residence** | Peri urban | 46 (9.5) | 47 (9.6) |
| | Rural | 340 (70.7) | 361 (73.4) |
| | Urban | 95 (19.8) | 84 (17.0) |
| **Socio Economic Status (SES)** | Mean | 8.5 | 10 |
| | Median | 10 | 10 |
| **Wealth quintile** | Poorest | 108 (22.5) | 116 (22.4) |
| | Poor | 117 (24.3) | 121 (24.6) |
| | Middle | 131 (27.2) | 130 (26.4) |
| | Rich | 75 (15.6) | 77 (15.7) |
| | Richest | 50 (10.4) | 48 (9.8) |
| **Community factors** | | | |
| **Women's and men's groups** | No | 14 (2.9) | 430 (87.4) |
| | Yes | 467 (97.1) | 62 (12.6) |
| **Community governance structures** | Fully functional | 398 (82.7) | 169 (34.3) |
| | Non-functional | 51 (10.6) | 309 (62.8) |
| | Partially functional | 32 (6.7) | 14 (2.9) |
| **Faith-based organizations (FBOs)** | No | 137 (28.5) | 255 (51.8) |
| | Yes | 344 (71.5) | 237 (48.2) |
| **Social networks** | No | 125 (26.0) | 315 (64.0) |
| | Yes | 356 (74.0) | 177 (36.0) |
| **Community women's literacy** | High | 73 (15.2) | 77 (15.7) |
| | Low | 54 (11.2) | 108 (22.0) |
| | Medium | 354 (73.6) | 307 (62.4) |
| **Trained community health workers** | No | 19 (4.0) | 131 (26.6) |
| | Yes | 462 (96.0) | 361 (73.4) |
| **Community health workers trained in newborn care** | No | 157 (32.6) | 299 (60.8) |
| | Yes | 324 (67.4) | 193 (39.2) |

*Variables statistically significant at p value < 0.05

Just over half of the newborns were female (50.9% in the intervention group and 50.4% in the control group). Skilled birth attendants conducted deliveries for 76.5% of neonates in intervention areas and 77.8% in control areas, with these births taking place at health facilities. Conversely, deliveries outside health facilities (including home births and other locations) accounted for about 23.5% in the intervention group and 22.4% in the control group. It is important to highlight that the category "other location" mostly comprises infants born before arrival at a health facility. (Table 5).

**Table 4: Demographic characteristics of women of childbearing age by intervention allocation, 2020-2021 (N=973)**

| **Mother's factors** | | **Intervention n = 481 (%)** | **Control n = 492 (%)** |
|---|---|---|---|
| **Age** | Median | **29** | **29** |
| **Age category** | 15-24 years | 131 (27.23) | 146 (29.67) |
| | 25-49 years | 350 (72.77) | 346 (70.33 |
| **Marital status** | Married | 305 (63.41) | 311 (63.21) |
| | Never married | 103 (21.41) | 108 (21.95) |
| | Divorced/ separated | 43 (8.94) | 42 (8.54) |
| | Widowed | 30 (6.24) | 31 (6.30) |
| **Maternal religion** | Conservative | 164 (34.10) | 184 (37.40) |
| | Non-conservative | 218 (45.32) | 218 (44.31) |
| | Traditionalist | 25 (5.20) | 24 (4.88) |
| | Other | 74 (15.38) | 66 (13.41) |
| **Education level** | None | 5 (1.04) | 5 (1.02) |
| | Primary | 128 (26.61) | 119 (24.19) |
| | Secondary | 308 (64.03) | 324 (65.85) |
| | Tertiary | 40 (8.32) | 44 (8.94) |
| **Employment status** | Formal employment | 29 (6.03) | 31 (6.30) |
| | Self-employment | 82 (17.05) | 85 (17.28) |
| | Farmer | 170 (35.34) | 180 (34.96) |
| | Casual labor | 128 (26.61) | 129 (24.59) |
| | Panning | 72 (14.97) | 67 (13.62) |
| **Parity** | Ever pregnant | 372 (77.34) | 373 (75.81) |
| | Never pregnant | 109 (22.66) | 119 (24.19) |
| **Desire for pregnancy** | Planned | 264 (53.66) | 263 (54.68) |
| | Not planned | 228 (46.34) | 218 (45.32) |
| **Birth interval** | <2 years | 363 (75.47) | 373 (75.81) |
| | >2 years | 118 (24.53) | 119 (24.19) |
| **Polygamous marriage** | No | 345 (71.7) | 352 (71.5) |
| | Yes | 136 (28.3) | 140 (28.5) |

**Table 5: Characteristics of neonate by intervention allocation, 2019-2020 (n=973)**

| **Neonate's factors** | | **Intervention n = 481 (%)** | **Control n = 492 (%)** |
|---|---|---|---|
| **Sex** | Boy | 236 (49.06) | 244 (49.59) |
| | Girl | 245 (50.94) | 248 (50.41) |
| **Place of birth** | Health Facility | 368 (76.51) | 382 (77.64) |
| | Home | 82 (17.05) | 82 (16.67) |
| | Other (Shrine) | 31 (6.44) | 28 (5.69) |
| **Birth weight less than 2500g** | No | 419 (87.11) | 402 (81.71) |
| | Yes | 62 (12.89) | 90 (18.29) |
| **Mother's perceived baby size** | Small | 175 (36.38) | 184 (37.40) |
| | Average | 213 (44.28) | 209 (42.48) |
| | Large | 93 (19.33) | 99 (20.12) |
| **Birth order 1** | No | 387 (80.46) | 381 (77.44) |
| | Yes | 94 (19.54) | 111 (22.56) |
| **Live birth 2 to 4** | No | 201 (42.79) | 235 (47.76) |
| | Yes | 280 (58.21) | 257 (52.24) |
| **Live births 5 plus** | No | 308 (64.03) | 390 (79.27) |
| | Yes | 173 (35.97) | 102 (20.73) |
| **Baby name** | No | 425 (88.36) | 439 (89.23) |
| | Yes | 56 (11.64) | 53 (10.77) |

*Variables statistically significant at p value < 0.05

**Service delivery factors at institutional and community level**

Home visits by VHWs were notably higher in intervention areas (72.8%) compared to control areas (39.2%). Likewise, a higher proportion of mothers in the modified women's and men's group intervention areas completed the recommended eight antenatal care (ANC) contacts (55.5% versus 44.4% in control areas), initiated ANC early—before 12 weeks of pregnancy (62.9% versus 45.3%), identified danger signs in newborns (71.4% versus 54.3%), and practiced kangaroo mother care/skin-to-skin contact at home (72.7% versus 41.4%), compared to mothers in control areas.

**Table 6: Service delivery characteristics by intervention allocation, 2020-2021 (n=973)**

| **Service delivery factors** | | **Intervention n = 481 (%)** | **Control n = 492 (%)** |
|---|---|---|---|
| **Skilled Birth Attendant** | No | 113 (23.49) | 109 (22.15) |
| | Yes | 368 (76.51) | 383 (77.85) |
| **Post natal care (PNC)** | Clinic <72 hours | 49 (10.19) | 74 (15.04) |
| | Clinic 72 hours | 325 (67.57) | 317 (64.43) |
| | Home Visit Day 3 by VHW | 88 (18.30) | 35 (7.11) |
| | No home visit | 19 (3.95) | 66 (13.41) |
| **Baby experienced danger signs** | No | 147 (30.56) | 242 (49.19) |
| | Yes | 334 (69.44) | 250 (50.81) |
| **Home visit by VHWs** | No | 131 (27.23) | 299 (60.77) |
| | Yes | 350 (72.77) | 193 (39.23) |
| **Antenatal care contacts** | 8 ANC plus | 205 (44.50) | 247 (55.60) |
| | Less than 8 ANC | 256 (55.50) | 197 (44.40) |
| **Early ANC booking** | No | 171 (37.10) | 243 (54.70) |
| | Yes | 290 (62.90) | 201 (45.30) |
| **Identification of danger signs** | No | 132 (28.60) | 203 (45.70) |
| | Yes | 329 (71.40) | 241 (54.30) |
| **Kangaroo mother care at home** | No | 126 (27.30) | 260 (58.60) |
| | Yes | 335 (72.70) | 184 (41.40) |
| **Clean cord care** | No | 128 (27.80) | 260 (58.60) |
| | Yes | 333 (72.20) | 184 (41.40) |
| **Exclusive breastfeeding** | **No** | 123 (26.70) | 114 (25.70) |
| | **Yes** | 338 (73.30) | 330 (74.30) |

**Causes and time of neonatal deaths**

This study analyzed neonatal verbal autopsy data to determine the causes and timing of neonatal deaths, using community registers from the study period. However, due to travel restrictions related to the COVID-19 pandemic, designated senior midwives were unable to conduct interviews with caregivers. As a result, the determination of causes of death relied mainly on health facility records, since most neonates were delivered in health institutions. The data on neonatal death causes were primarily collected to categorize preventable deaths and assess the impact of the community health system.

In terms of the causes of neonatal deaths, prematurity was the leading factor, responsible for over 50% of the cases, followed by birth asphyxia and severe infections. Regarding the timing of these deaths, Figure 4 shows that most occurred within the first week of life, with an alarming 80% of neonatal deaths occurring on the very first day.

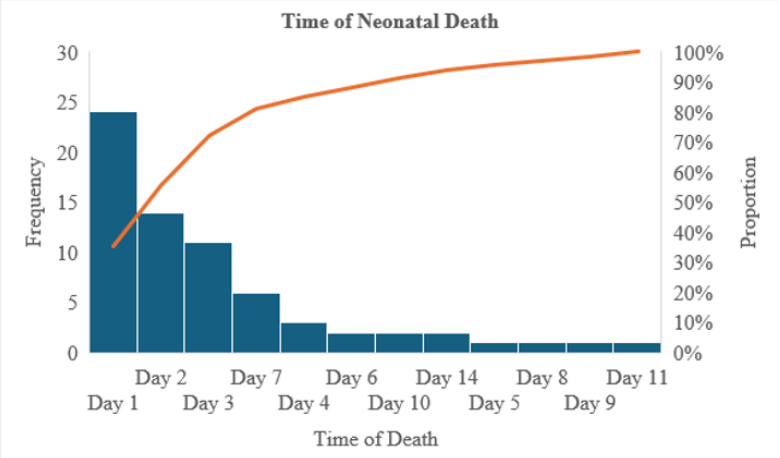


**Figure 4: Reported day of deaths for neonatal deaths, 2020-2021**

**Community health system factors associated with reducing preventable neonatal deaths**

This analysis investigated the factors influencing preventable neonatal deaths in the context of community health systems. The study analysed 46 variables to identify key predictors and evaluate the effectiveness of the modified women's and men's group action interventions. The results showed that household factors such as wealth quintile ($X^2$ = 53.3, p <0.0001), family religion ($X^2$ = 27.05, p <0.0001), maternal factors including age, marital status, maternal education, maternal employment status, maternal religion, birth interval and polygamous marriage ($X^2$ =70.7; 15.5; 41.1; 14.8; 27.0; 123.5 and 18.0, p <0.0001), respectively were significantly associated with neonatal death. Similarly, neonatal factors including sex of neonate ($X^2$ = 16.1, p <0.0001), birth weight less than 2,500g ($X^2$ = 129.6, p <0.0001), mother's perceived birth size ($X^2$ = 61.2, p <0.0001) and birth complications ($X^2$ = 66.3, p <0.0001) were significantly associated with neonatal deaths. Service delivery factors (8 antenatal care contacts ($X^2$ = 16.78, p <0.0001), early antenatal care booking before 12 weeks ($X^2$ = 32.49, p <0.0001), early identification of danger signs by mothers (($X^2$ = 45.62, p <0.0001), home visits by the VHWs ($X^2$ = 21.64, p <0.0001), were also significantly associated with neonatal deaths. To directly answer the focus of the study, community level factors including modified women's and men's action groups ($X^2$ = 20.1, p <0.0001), social networks ($X^2$ = 27.5, p <0.0001), presence of a trained community health worker in the village ($X^2$ = 31.1, p <0.0001), community governance structures (Health Centre Committees and Village Health Committees - ($X^2$ = 48.7, p <0.0001) and community women's literacy (X2 = 99.63, p<0.0001) were significantly associated with neonatal deaths (Table 8). Also important to note is the time of neonatal death ($X^2$ = 973, p <0.0001), where 89.7% died less than 7 days after birth was associated with neonatal death.

**Table 7: Community health system predictors of neonatal deaths, Mashonaland West province, 2020-2021.**

| Variables | Total N (%) | Deaths N (%) | | Survived N (%) | | Chi-square | p-Value |
|---|---|---|---|---|---|---|---|
| | | Intervention | Control | Intervention | Control | | |
| **Household factors** | | | | | | | |
| **Place of residence** | | | | | | | |
| Rural | 701 (72.0) | 2 (10.0) | 5 (10.4) | 44 (9.5) | 42 (9.5) | 9.6 | 0.008 |
| Urban | 179 (18.4) | 16 (80.0) | 42 (87.5) | 324 (70.3) | 319 (71.8) | | |
| Peri Urban | 93 (9.6) | 2 (10.0) | 1 (2.1) | 93 (20.2) | 83 (18.7) | | |
| **Wealth quintile** | | | | | | | |
| Poorest | 220 (22.6) | 13 (65.0) | 26 (54.2) | 95 (20.6) | 86 (19.4) | 53.26 | <0.0001 |
| Poor | 238 (24.5) | 3 (15.0) | 11 (22.9) | 114 (24.7) | 110 (24.8) | | |
| Middle | 265 (27.2) | 1 (5.0) | 9 (18.8) | 130 (28.2) | 125 (28.2) | | |
| Rich | 152 (15.6) | 2 (10.0) | 1 (2.1) | 73 (15.8) | 76 (17.1) | | |
| Richest | 98 (10.1) | 1 (5.0) | 1 (2.1) | 49 (10.6) | 47 (10.6) | | |
| **Family religion** | | | | | | | |
| Yes | 401 (41.2) | 4 (20.0) | 16 (33.3) | 284 (61.6) | 268 (60.4) | 27.05 | <0.0001 |
| No | 572 (58.8) | 16 (80.0) | 32 (66.7) | 177 (38.4) | 176 (39.6) | | |
| **Community factors** | | | | | | | |
| **Baby name** | | | | | | | |
| Yes | 109 (11.2) | 6 (30.0) | 11 (22.9) | 50 (10.8) | 42 (9.5) | 12.54 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| No | 864 (88.8) | 14 (70.0) | 37 (77.1) | 411 (89.2) | 402(90.5) | | <0.0001 * |
| **Modified women's and men's group meetings** | | | | | | | |
| Yes | 477 (49.0) | 20 (100.0) | 0 (0.0) | 461 (100.0) | 0 (0.0) | 20.13 | <0.0001 * |
| No | 496 (51.0) | 0 (0.0) | 48 (100.0) | 0 (0.0) | 444 (100.0) | | |
| **Social networks** | | | | | | | |
| Yes | 533 (54.8) | 7 (35.0) | 9 (18.8) | 349 (75.7) | 168 (37.8) | 27.48 | <0.0001 * |
| No | 440 (45.2) | 13 (65.0) | 39 (81.2) | 112 (24.3) | 276 (62.2) | | |
| **Presence of Trained Village health worker** | | | | | | | |
| Yes | 823 (84.6) | 15 (75.0) | 26 (54.2) | 447 (97.0) | 335 (75.5) | 31.11 | <0.0001 * |
| No | 150 (15.4) | 5 (25.0) | 22 (45.8) | 14 (3.0) | 109 (24.5) | | |
| **VHW trained newborn care** | | | | | | | |
| Yes | 517 (53.1) | 8 (40.0) | 11 (22.9) | 316 (68.5) | 182 (41.0) | 17.56 | <0.0001 * |
| No | 456 (46.9) | 12 (60.0) | 37 (77.1) | 145 (31.5) | 262 (59.0) | | |
| **Community governance structures** | | | | | | | |
| Fully functional | 438 (45.0) | 3 (15.0) | 0 (0.0) | 389 (84.4) | 46 (10.4) | 48.73 | <0.0001 * |
| Partially functional | 391 (40.2) | 7 (35.0) | 10 (20.8) | 26 (5.6) | 101 (22.7) | | |
| Non-functional | 144 (14.8) | 10 (50.0) | 38 (79.2) | 46 (10.0) | 297 (66.9) | | |
| **Community women's literacy** | | | | | | | |
| Low | 171 (17.6) | 1 (5.0) | 1 (2.1) | 73 (15.8) | 77 (17.3) | 99.63 | <0.0001 * |
| Medium | 650 (66.8) | 14 (70.0) | 28 (58.3) | 46 (10.0) | 83 (18.7) | | |
| High | 152 (15.6) | 5 (25.0) | 19 (39.6) | 342 (74.2) | 284 (64.0) | | |
| **Service delivery factors** | | | | | | | |
| **Antenatal care contacts** | | | | | | | |
| 8 ANC plus | 469 (48.2) | 15 (75.0) | 37 (77.1) | 205 (44.5) | 247 (55.6) | 16.78 | <0.0001 |
| Less than 8 ANC contacts | 504 (51.8) | 5 (25.0) | 11 (22.9) | 256 (55.5) | 197 (44.4) | | |
| **Early ANC booking** | | | | | | | |
| Yes | 503 (51.7) | 17 (85.0) | 39 (81.3) | 171 (37.1) | 243 (57.4) | 32.49 | <0.0001 |
| No | 470 (48.3) | 3 (15.0) | 9 (18.8) | 290 (62.9) | 201 (45.3) | | |
| **Identification of danger signs** | | | | | | | |
| Yes | 584 (60.0) | 5 (25.0) | 9 (18.8) | 329 (71.4) | 241 (54.3) | 45.62 | <0.0001 * |
| No | 389 (40.0) | 15 (75.0) | 39 (81.3) | 132 (28.6) | 203 (45.7) | | |
| **Postnatal care** | | | | | | | |
| PNC 72 hours | 642 (66.0) | 4 (20.0) | 16 (33.3) | 45 (9.8) | 58 (13.1) | 21.56 | <0.0001 |
| PNC less than 72 hours | 123 (12.6) | 11 (55.0) | 25 (52.1) | 314 (68.1) | 292 (65.8) | | |
| Home visit by VHWs | 123 (12.6) | 3 (15.0) | 1 (2.1) | 85 (18.4) | 34 (7.7) | | |
| No home visit | 85 (8.7) | 2 (10.0) | 6 (12.5) | 17 (3.7) | 60 (13.5) | | |
| **Place of birth** | | | | | | | |
| Health Facility | 750 (77.1) | 15 (75.0) | 41 (85.4) | 353 (76.6) | 341 (76.8) | 29.68 | <0.0001 |
| Home | 164 (16.9) | 1 (5.0) | 5 (10.4) | 81 (17.6) | 77 (17.3) | | |
| Other | 59(6.0) | 4 (10.0) | 2 (4.2) | 27 (5.9) | 26 (5.9) | | |
| **Home visit by VHW at Day 3** | | | | | | | |
| Yes | 542 (55.7) | 12 (60.0) | 37 (77.1) | 120 (26.0) | 262 (59.0) | 21.64 | <0.0001 * |
| No | 431 (44.3) | 8 (40.0) | 11 (22.9) | 341 (74.0) | 182 (41.0) | | |
| **Kangaroo mother care at home** | | | | | | | |
| Yes | 549 (56.4) | 8 (40.0) | 30 (62.5) | 126 (27.3) | 260 (58.6) | 3.98 | 0.046* |
| No | 424 (43.6) | 12 (60.0) | 18 (37.5) | 335 (72.7) | 184 (41.4) | | |
| **Clean Cord Care** | | | | | | | |
| Yes | 547 (56.2) | 8 (40.0) | 30 (62.5) | 128 (27.8) | 260 (58.6) | | 0.050 |
| No | 426 (43.8) | 12 (60.0) | 18 (37.5) | 333 (72.2) | 184 (41.4) | | |
| **Exclusive breastfeeding** | | | | | | | |
| Yes | 712 (73.2) | 7 (35.0) | 15 (31.2) | 107 (23.2) | 114 (25.7) | 2.23 | 0.136 |
| No | 261 (26.8%) | 13 (65.0) | 33 (68.8) | 354 (76.8) | 330 (74.3) | | |

*Community health system variables

*Variables statistically significant at p value < 0.05

**Table 8: Community health system predictors of neonatal deaths, Mashonaland West province, 2020-2021.**

| Variables | Total N (%) | Deaths N (%) | | Survived N (%) | | Chi-square | p-Value |
|---|---|---|---|---|---|---|---|
| | | Intervention | Control | Intervention | Control | | |
| **Maternal factors** | | | | | | | |
| **Age category** | | | | | | | |
| 15-24 years | 277 (28.5) | 11 (55.0) | 22 (45.8) | 120 (26.0) | 124 (27.9) | 70.71 | <0.0001 |
| 25-49 years | 696 (71.5) | 9 (45.0) | 26 (54.2) | 341 (74.0) | 320 (72.1) | | |
| **Maternal education** | | | | | | | |
| None | 9 (0.9) | 2 (10.0) | 1 (2.1) | 3 (0.06) | 3 (0.07) | 41.15 | <0.0001 |
| Primary | 248 (25.5) | 12 (60.0) | 24 (50.0) | 116 (25.2) | 96 (21.6 | | |
| Secondary | 632 (65.0) | 6 (30.0) | 21 (43.8) | 302 (65.5) | 303 (68.2) | | |
| Tertiary | 84 (8.6) | 0 | 2 (4.2) | 40 (8.7) | 42 (9.5) | | |
| **Maternal employment status** | | | | | | | |
| Farmers | 353 (36.3) | 6 (30.0) | 24 (50.0) | 167 (36.2) | 164 (36.9) | 14.79 | 0.005 |
| Casual labor | 254 (26.1) | 6 (30.0) | 16 (33.3) | 119 (25.8) | 105 (23.6) | | |
| Self-employment | 167 (17.2) | | 2 (4.2) | 77 (16.7) | 85 (19.1) | | |
| Panning | 139 (14.3) | 3 (15.0) | 6 (12.5) | 69 (15.0) | 61 (13.7) | | |
| Formal employment | 60 (6.2) | 5 (25.0) | 0 | 29 (6.3) | 29 6.5) | | |
| **Maternal religion** | | | | | | | |
| Non conservative | 436 (44.8) | 13 (65.0) | 31 (64.6) | 151 (32.8) | 153 (34.5) | 27.05 | <0.0001 |
| Conservative | 348 (35.8) | 3 (15.0) | 12 (25.0) | 215 (46.6) | 206 (46.4) | | |
| Other | 140 (14.4) | 3 (15.0) | 4 (8.3) | 71 (15.4) | 62 (14.0) | | |
| Traditionalist | 49 (5.0) | 1 (5.0) | 1 (2.1) | 24 (5.2) | 23 (5.2) | | |
| **Desire for pregnancy** | | | | | | | |
| Yes | 527 (54.2) | 8 (40.0) | 18 (37.5) | 210 (45.6) | 210 (47.3) | 1.39 | 0.239 |
| No | 446 (45.8) | 12 (60.0) | 30 (62.5) | 251 (54.4) | 234 (52.7) | | |
| **Birth interval** | | | | | | | |
| Less than 24 months | 237 (24.4) | 3 (15.0) | 10 (20.8) | 360 (78.1) | 363 (81.8) | 123.5 | <0.0001 |
| More than 24 months | 736 (75.6) | 17 (85.0) | 38 (79.2) | 101 (21.9) | 81 (18.2) | | |
| **Parity** | | | | | | | |
| Ever pregnant | 745 (76.6) | 17 (85.0) | 41 (85.4) | 355 (77.0) | 332 (74.8) | 2.6 | 0.107 |
| Never pregnant | 228 (23.4) | 3 (15.0) | 7 (4.6) | 106 (23.0) | 112 (25.2) | | |

**Table 9: Community health system predictors of neonatal deaths, Mashonaland West province, 2020-2021**

| Variables | Total N (%) | Deaths N (%) | | Survived N (%) | | Chi-square | p-Value |
|---|---|---|---|---|---|---|---|
| | | Intervention | Control | Intervention | Control | | |
| **Neonatal factors** | | | | | | | |
| **Sex** | | | | | | | |
| Girl | 493 (50.7) | 4 (20.0 | 14 (29.2) | 241 (52.3) | 234 (52.7) | 16.1 | <0.0001 |
| Boy | 480 (49.3) | 16 (80.0) | 34 (70.8) | 220 (47.7) | 210 (47.3) | | |
| **Birth Weight** | | | | | | | |
| Less than 2500g | 152 (15.6) | 12 (60.0) | 32 (66.7) | 50 (10.8) | 58 (13.1) | 129.65 | <0.0001 |
| 2500g and above | 821 (84.4) | 8 (40.0) | 16 (33.3) | 411 (89.2) | 386 (86.9) | | |
| **Mother's perceived birth size** | | | | | | | |
| Small | 359 (36.9) | 17 (85.0) | 38 (79.2) | 158 (34.3) | 146 (32.9) | 61.19 | <0.0001 |
| Average | 422 (43.4) | 0 (0.0) | 7 (14.6) | 213 (46.2) | 202 (45.5) | | |
| Large | 192 (19.7) | 3 (15.0) | 3 (6.2) | 90 (19.5) | 96 (21.6) | | |
| **Birth complications** | | | | | | | |
| Yes | 286 (29.4) | 15 (75.0) | 35 (72.9) | 121 (26.2) | 115 (25.9) | 66.35 | <0.0001 |
| No | 687 (70.6) | 5 (25.0) | 13 (27.1) | 340 (73.8) | 329 (74.1) | | |
| **Skilled Birth Attendant** | | | | | | | |
| Yes | 751 (77.2) | 15 (75.0) | 41 (85.4) | 353 (76.6) | 342 (77.0) | 0.82 | 0.366 |
| No | 222 (22.8) | 5 (25.0) | 7 (14.6) | 108 (23.4) | 102 (23.0) | | |
| **Live births 5 plus** | | | | | | | |
| Yes | 275 (28.3) | 4 (20.0) | 18 (37.5) | 169 (36.7) | 84 (18.9) | 0.41 | 0.524 |
| No | 698 (71.7) | 16 (80.0) | 30 (62.5) | 292 (63.3) | 360 (81.1) | | |
| **Birth order 1** | | | | | | | |
| Yes | 205 (21.1) | 3 (15.0) | 13 (27.1) | 91 (19.7) | 98 (22.1) | 0.13 | 0.718 |
| No | 768 (78.9) | 17 (85.0) | 35 (72.9) | 370 (80.3) | 346 (77.9) | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Family Influence** | | | | | | | |
| Yes | 448 (46.0) | 15 (75.0) | 40 (83.3) | 190 (41.2) | 203 (45.7) | 34.23 | <0.0001* |
| No | 525 (54.0) | 5 (25.0) | 8 (16.7) | 271 (58.8) | 241 (54.3) | | |

*Variables statistically significant at p value < 0.05

**Multivariable community health system prediction model, for reducing preventable neonatal deaths**

The multiple logistic models showed that birth interval less than 2 years, postnatal care (PNC) less than 72 hours, livebirths 5 plus, not participating in modified women's and men's group meetings, sex of the child, early antenatal care (ANC) booking, exclusive breastfeeding (EBF) and kangaroo mother care (KMC) were the predictors of preventable neonatal deaths.

The neonates born from mothers whose preceding birth interval was less than 24 months were 60.8% lower risk of neonatal death [ARR = 0.608; 95% CI (0.51-0.70), $p < 0.0001$] in the modified women's and men's group intervention compared to the control group. In other words, the modified women's and men's group intervention appeared to reduce the risk of neonatal death by approximately 39.2%. The neonates with a birth weight of less than 2,500g were 1.5 times (ARR=1.47) more likely to die compared to those with birth weight more than 2,500g, but had a lower risk of neonatal death [ARR = 0.528; 95% CI (0.41-0.64), $p < 0.0001$] in the intervention group compared to control group. There was a reduction in the risk of neonatal deaths among girls [ARR = -0.261; 95% CI (0.37-0.15), $p < 0.0001$] born to mothers who participated in these modified groups. Specifically, the likelihood of neonatal death decreased by approximately 26.1% in girls compared to those who do not participate, after adjusting for other variables in the model.

Newborn babies whose caregivers participated in the modified women's and men's group learning and action meetings had lower likelihood of dying [ARR= 0.215; 95% CI (0.10–0.33), $p < 0.0001$] compared to mothers in control group. Similarly, newborn babies whose mothers practiced kangaroo mother care [ARR= -0.132; 95% CI (-0.25–0.01), $p = 0.046$] were protected from neonatal deaths and had 13.2% lower risk in the intervention compared to control group (Table 11).

In a focus group discussion with women of childbearing age, family influence was reported as having negative impact on the mother where she is forced to get pregnant which might result in birth intervals of less than 24 months.

**Table 10: Multiple Logistic Regression community health system prediction model, for reducing preventable neonatal deaths, Mashonaland West Province, 2020-2021**

| | 95% Confidence Interval | | |
|---|---|---|---|
| **Variable** | **RR (95% CI)** | **ARR (95% CI)** | **p-value** |
| **Place of residence** | | | |
| Urban | | 1 | |
| Rural | 1.20 (1.08-1.34) | 0.142 (0.05-0.23) | 0.008 |
| **Sex** | | | |
| Boy | | 1 | |
| Girl | 0.50 (0.34-0.75) | -0.260 (-0.37 – 0.15) | <0.0001 |
| **Birth interval less than 2 years** | | | |
| No | | 1 | |
| Yes | 4.02 (3.38-4.79) | 0.608 (0.51-0.70) | <0.0001 |
| **Birth weight less than 2500g** | | | |
| No | | 1 | |
| Yes | 5.42 (4.23-6.96) | 0.528 (0.41-0.64) | <0.0001 |
| **Complications** | | | |
| No | | 1 | |
| Yes | 2.82 (2.36-3.38) | 0.475 (0.37-0.58) | <0.0001 |
| **Live births 5 plus** | | | |
| No | | 1 | |
| Yes | 1.16 (0.81-1.66) | 1.71(1.59 – 1.80) | <0.0001 |
| **Community women literacy** | | | |
| High | | 1 | |
| Low | 4.33 (3.39-5.54) | 0.475 (0.36-0.59) | <0.0001 |
| **Danger signs recognition at household level** | | | |
| No | | 1 | |
| Yes | 0.33 (0.20-0.52) | -0.424 (-0.53-0.32) | <0.0001 |
| **Family influence** | | | |
| Family influence on pregnancy | | 1 | |

| | | | |
|---|---|---|---|
| No family influence | 1.86 (1.62-2.14) | 0.375 (0.28-0.47) | <0.0001 |
| **Early ANC before 12 weeks** | | | |
| No | | | |
| Yes | 0.33 (0.19-0.55) | -0.329 (-0.46-0.27) | <0.0001 |
| **Social networks** | | | |
| No | | 1 | |
| Yes | 0.41 (0.27-0.63) | -0.336 (-0.44-0.23) | <0.0001 |
| **Community Governance fully functional** | | | |
| No | | 1 | |
| Yes | 1.86 (1.56-2.22) | 0.327 (0.21-0.44) | <0.0001 |
| **Socio economic status (SES)** | | | |
| High | | 1 | |
| Low | 2.65 (2.04-3.43) | 0.329 (0.21-0.45) | <0.0001 |
| **Maternal religion** | | | |
| Non-conservative | | 1 | |
| Conservative | 1.81 (1.52-2.15) | 0.316 (0.20-0.43) | <0.0001 |
| **Polygamous marriage** | | | |
| No | | 1 | |
| Yes | 1.93 (1.50-2.49) | 0.248 (0.13-0.37) | <0.0001 |
| **Modified women's and men's group** | | | |
| Control | | 1 | |
| Intervention | 1.44 (1.22-1.70) | 0.215 (0.10-0.33) | 0.001 |
| **PNC less than 72 hours** | | | |
| No | | 1 | |
| Yes | 2.58 (1.71-3.90) | 0.180 (0.07-0.29) | <0.0001 |
| **Baby name** | | | |
| Yes | | 1 | |
| No | 2.46 (1.56-3.88) | 0.148 (0.04-0.25) | <0.0001 |
| **Kangaroo mother care (KMC)** | | | |
| No | | 1 | |
| Yes | 0.77 (0.59-1.01) | -0.132 (-0.25-0.01) | 0.046 |
| **Clean Cord Care** | | | |
| No | | 1 | |
| Yes | 0.77 (0.59-1.02) | -0.130 (-0.21-0.03) | 0.050 |
| **Exclusive breastfeeding (EBF)** | | | |
| No | | 1 | |
| Yes | 0.88 (0.73-1.05) | -0.132 (-0.25 – 0.01) | 0.136 |
| **Number of modified women's and men's group meetings** | | | |
| Less than 3 meetings | | 1 | |
| 3 meetings and above | 4.99 (2.02-12.34) | 0.071 (0.00-0.14) | <0.0001 |

*Variables statistically significant at p value < 0.05

**Model Performance**

The machine learning models demonstrated varying predictive performance. The Random Forest model outperformed other approaches with higher accuracy (84.3%), better sensitivity (91.3%) and specificity (80.3%) and stronger discriminative ability (AUC: 0.842) (Table 12).

**Table 11: Predictive model performance for reducing preventable neonatal deaths, Mashonaland West, 2020-2021**

| Model | Accuracy | Sensitivity | Specificity | ROC AUC |
|---|---|---|---|---|
| Logistic Regression | 0.615 | 0.611 | 0.622 | 0.615 |
| Random Forest | 0.843 | 0.913 | 0.803 | 0.842 |
| Decision Tree | 0.830 | 0.910 | 0.790 | 0.830 |
| Support Vector Machine | 0.686 | 0.750 | 0.670 | 0.686 |

***ROC AUC:** Receiver Operating Characteristic Area Under the Curve, is a performance measurement for classification models at various threshold settings

**Multilevel Logistic Regression for predicting preventable neonatal deaths**

The multilevel model revealed important hierarchical effects. In relation to neonatal factors small birth size less than 2,500g showed increased odds of death (AOR: 1.76, 95% CI: 0.86-3.61). The maternal factors including birth intervals <24 months showed substantially higher odds (AOR: 3.58, 95% CI: 1.56-8.22) compared to longer intervals with number of children ever born remained a significant predictor (AOR: 1.40, 95% CI: 1.22-1.60). Community level factors persisted at weighted three-level random intercept with low community women's literacy (AOR = 2.35, 95% CI: 1.25, 4.41) increasing the odd of neonatal death. In the same vein, newborns delivered in a community with VHWs (AOR: 0.64, 95% CI: 0.44, 0.94) were at 36% lower risk of neonatal death compared to the control group. Similarly, newborn babies in communities with a VHW trained in newborn care (AOR: 0.51, 95% CI: 0.33, 0.77) were associated with a reduced likelihood of the neonatal death (49%). Household-level clustering accounted for 28.6% of the variation in Model 3. Furthermore, for model fit: Model 2 (two-level with covariates) demonstrated the best fit with the lowest AIC (810.06) and BIC (887.04) values, compared to the null model (AIC: 1362.00, BIC: 1375.36) and three-level model (AIC: 856.27, BIC: 933.24).

Our analysis also identified several important interaction effects where VHW presence + Early ANC (2.5x multiplier effect), VHW + danger signs recognition (2.1x multiplier) and institutionalization + social networks (1.8x multiplier). Overall, communities with comprehensive intervention packages showed 43% greater reduction in neonatal deaths compared to partial implementation.

**Table 12: Multilevel Logistic Regression for predicting preventable neonatal deaths through community health system, Mashonaland West**

| Variable | Model 1 | OR (95%CI) | Model 2 | OR (95%CI) | p-value | Model 3 | OR (95%CI) | p-value | Model 4 | OR (95%CI) | p-value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Neonatal factors** | | | | | | | | | | | |
| **Birth weight** | | | | | | | | | | | |
| >2,500g | | | 1.00(Ref) | | | | | | | | |
| < 2,500g | | | 1.76 | (0.79, 3.67) | 0.175 | 1.76 | (0.86,3.61) | 0.124 | 1.68 | (0.82, 3.45) | 0.156 |
| **Maternal factors** | | | | | | | | | | | |
| **Preceding birth interval** | | | | | | | | | | | |
| <24 months | | | 3.05 | (1.18, 7.88) | 0.021 | 3.58 | (1.56,8.22) | 0.003 | 2.94 | (1.28, 6.78) | 0.011 |
| 24-47 months | | | 2.89 | (1.41, 5.91) | 0.004 | 3.08 | (1.63,5.81) | 0.001 | 2.77 | (1.46, 5.24) | 0.002 |
| 48+ months | | | 1.00(Ref) | | | 1.00(Ref) | | | | | |
| **Community factors** | | | | | | | | | | | |
| **Community women's literacy** | | | | | | | | | | | |
| Low | | | 2.47 | (1.27, 4.82) | 0.008 | 2.73 | (1.46,5.10) | 0.002 | 2.35 | (1.25, 4.41) | 0.008 |
| **VHW presence** | | | | | | | | | | | |
| No | | | 1.00(Ref) | | | 1.00(Ref) | | | 1.00 (Ref) | | |
| Yes | | | | | | | | | 0.64 | (0.44, 0.94) | 0.022 |
| **VHW Trained in Newborn Care** | | | | | | | | | | | |
| No | | | 1.00(Ref) | | | 1.00(Ref) | | | 1.00(Ref) | | |
| Yes | | | | | | | | | 0.51 | (0.33, 0.77) | 0.002 |
| **VHW Home Visits** | | | | | | | | | | | |
| No | | | 1.00(Ref) | | | 1.00(Ref) | | | 1.00(Ref) | | |
| Yes | | | | | | | | | 0.68 | (0.48, 0.97) | 0.035 |
| **Interaction effects** | | | | | | | | | | | |
| VHW Presence × Birth Interval <24m | | | | | | 1.00(Ref) | | | 0.42 | (0.24, 0.73) | 0.002 |
| VHW Training × Early ANC | | | | | | 1.00(Ref) | | | 0.38 | (0.21, 0.69) | 0.001 |
| **Service delivery factors** | | | | | | | | | | | |
| Antenatal care | | | | | | | | | | | |
| No | | | 1.00(Ref) | | | 1.00(Ref) | | | 1.00(Ref) | | |
| Yes | | | 5.68 | (2.90,11.91) | <0.0001 | 5.12 | (2.69,9.76) | <0.0001 | 4.83 | (2.53, 9.21) | <0.0001 |

**Table 13: Weighted two and three-level random intercept logit model for predicting preventable neonatal deaths, Mashonaland West, 2020-2021**

| Variables | M1 | M1-SE | M2 | M2-SE | M3 | M3-SE | M4 | M4-SE |
|---|---|---|---|---|---|---|---|---|
| **Random effects Parameters** | | | | | | | | |
| Household level variance (SE) | 2.91 | (0.52) | 3.24 | (0.95) | 1.32 | (0.76) | 1.08 | (0.64) |
| Community level variance (SE) | | | | | 4.31 × 10^-33 | (4.34) × 10^-33 | 3.26 × 10^-33 | (3.87) × 10^-33 |
| **ICC OR VPC** | | | | | | | | |
| Household level ICC (%) | 46.97 | | 49.64 | | 28.6 | | 24.7 | |
| Community level ICC (%) | | | | | 9.35 × 10^-34 | | 7.42 × 10^-34 | |
| Model fit statistics | | | | | | | | |
| AIC | 1362.0 | | 810.06 | | 856.27 | | 764.35 | |
| BIC | 1375.36 | | 887.04 | | 933.24 | | 866.88 | |
| -2 log likelihood | -679.0 | | -393.03 | | -440.77 | | -364.18 | |

***Model 1** = weighted two-level null model, Model 2 = Weighted two-level random intercept with covariates, Model 3 = Weighted three-level random intercept with covariates, Model 4 = Weighted three-level random intercept with VHW variables and interactions.
***M1** = Model 1; M2 = Model 2; M3 = Model 3; M4 = Model 4
***M1-SE** = Model 1- Standard Error; M2-SE = Model 2- Standard Error; M3-SE= Model 3- Standard Error; M4-SE= Model 4- Standard Error
***AIC** = Akaike Information Criterion
***BIC** = Bayesian Information Criterion

# DISCUSSION

The ongoing issue of preventable neonatal deaths continues to be a significant public health concern, especially in resource-constrained environments like Zimbabwe. Robust community health systems have proven to be essential in tackling this issue, providing vital care and resources for pregnant women and their newborns. This study explored how community health systems contribute to the reduction of preventable neonatal deaths, framed within the context of pragmatism, a philosophical approach that prioritizes the practical implementation of concepts and the relevance of outcomes in evaluating the effectiveness of interventions.

Communities that effectively integrated all three key components of the community health system, namely, trained VHWs focused on newborn care, early antenatal care (ANC) booking by mothers, and the establishment of fully functional community governance structures experienced a 43% greater decrease in neonatal deaths compared to those with only partial implementation. Furthermore, an Area Under the Curve (AUC) value of 0.84 demonstrated perfect discrimination, indicating that the model accurately identified at-risk neonates with fewer false positives or false negatives (Table 12). This suggests that the model's factors were highly relevant and effectively captured the characteristics of vulnerable neonates. This finding suggests a strong likelihood that the intervention group significantly impacted neonatal mortality, as the probability of these results occurring by chance is extremely low. Therefore, there is compelling statistical evidence to reject the null hypothesis, which posited no effect of implementing community health systems on reducing preventable neonatal deaths.

One explanation for this outcome is the substantial role played by VHWs in community health initiatives, which significantly lowered neonatal mortality rates. This reduction can be attributed to VHWs' efforts in identifying pregnancies early, providing community education, and offering household support. Their interventions directly addressed risk factors associated with low maternal literacy and enhanced community monitoring at the household level, which tackled issues related to low birth weight. VHW support and home visits facilitated mothers' adherence to kangaroo mother care (KMC) (ARR: -0.132, 95% CI: -0.25 to -0.01, p = 0.046), albeit marginally. KMC is an evidence-based practice aimed at improving the health of low birth weight (LBW) infants, particularly those under 2500 grams. This method involves skin-to-skin contact between the mother (or another caregiver) and the infant, along with exclusive breastfeeding and other supportive measures. Such contact helps regulate the neonate's body temperature, which is vital for LBW babies who often struggle with thermoregulation. KMC has also been shown to promote breastfeeding, delivering essential nutrients and antibodies that are crucial for neonates. Close contact with the mother can enhance the infant's immune response, thereby reducing the risk of infections like neonatal sepsis. Research indicates that KMC can significantly lower neonatal mortality rates among LBW infants, particularly in low-resource settings. Similar findings emerged from a retrospective study in northern Ethiopia, revealing that newborns who received KMC were at a reduced risk for preterm neonatal mortality (AOR=0.08; 95% CI: 0.03 to 0.20) (Kahsay *et al.*, 2019; Girma and Nigussie, 2021; Adem, 2022). In Bangladesh,

a study found that 77% of mothers of low-birth-weight infants trained by community health workers practiced KMC at home (Tahir *et al.*, 2022).

These findings highlight the importance of effective implementation of the Ministry of Health and Child Care protocols, which stipulate that VHWs should conduct a minimum of five visits for small and sick newborns within the first 28 days. These visits are crucial for monitoring the infant's weight, growth, and general health. During these encounters, VHWs educate caregivers about warning signs such as difficulty breathing, lethargy, and refusal to feed, as well as when to seek medical assistance.

Additionally, early ANC plays a vital role by offering essential health evaluations, education, and timely medical care, which are critical for reducing risks associated with pregnancy and childbirth. The incorporation of fully functional community governance structures and social networks further enhances community support, strengthens referral systems, and mobilizes local resources for emergency obstetric care (Adongo and Ganle, 2023).

This analysis underscores the compounded benefits of integrating various components of community health systems and reinforces the idea that health interventions yield greater effectiveness when combined. This aligns with findings from the neonatal survival series, which identified 16 interventions that significantly improve neonatal survival when implemented in supportive environments. Therefore, packaging these interventions for scaling up through established delivery platforms, such as outreach programs, family and community-level initiatives, and facility-based care could potentially lead to more than double the impact in reducing neonatal mortality (Darmastadt *et al.*, 2005).

Overall, the findings from our multilevel modelling approach highlight the critical importance of both individual and contextual factors in neonatal mortality risk. The results demonstrate that interventions must address multiple levels - individual clinical factors (birth weight, birth interval, birth complications), maternal factor**s** (birth spacing), health system factors (antenatal care and postnatal follow-up) and community factor**s**: community women's health literacy Village health workers presence, effective coverage, skills in newborn care, and social support. Institutionalization of community governance operates at the community level and is considered a contextual variable that influences how VHW program's function.

The significant household and community-level variance components indicate the importance of contextual factors beyond individual characteristics. This supports a comprehensive approach to neonatal mortality reduction. Furthermore, the machine learning analysis complemented the traditional statistical approaches by identifying complex patterns and interactions that might be missed in conventional analyses. Key insights from this comparative analysis include:

1. **Consistency across methods**: The risk factors identified through traditional risk ratio analysis align with those from advanced machine learning approaches, strengthening confidence in our findings.
2. **Novel interactions**: Machine learning revealed important interactions that weren't evident in traditional regression models, particularly the synergistic effects between VHWs and early ANC.
3. **Hierarchical effects**: The multilevel model demonstrated significant clustering at household and community levels, highlighting the importance of contextual factors in reducing preventable neonatal deaths.
4. **Temporal risk profile**: Time of death emerged as the most important feature in machine learning models, emphasizing the critical period of the first 72 hours after birth.

**Key synergistic effects identified, Mashonaland West province, 2020-2021**

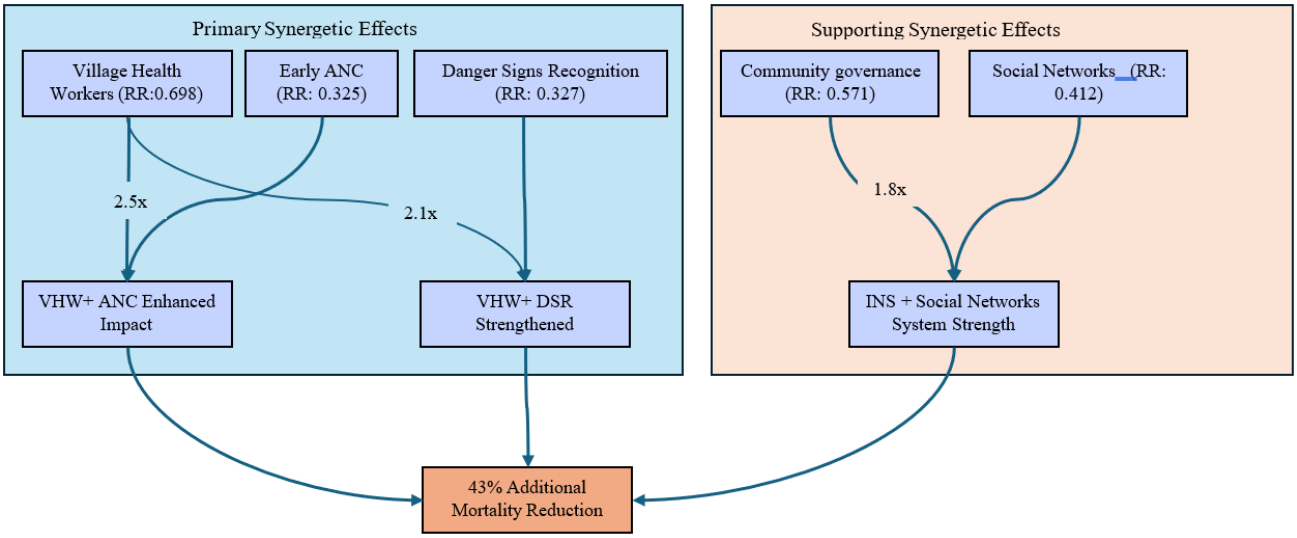


**Figure 5: Diagram of synergistic effects between community health system components on reducing neonatal deaths, Mashonaland West province, 2020-2021**

*VHWs (Village health workers)
*DSR (Danger sign recognition at household level)
* INS (Institutionalization of fully functional community governance structures plus social networks)

**Limitations**

This study faced limitations, including the impact of the COVID-19 pandemic, which hindered group meetings and may have skewed results. The one-year duration from pregnancy to post-delivery may have been insufficient to assess the intervention's effects on neonatal deaths. Additionally, the initiative lacked dedicated funding and relied on community resources, while the community health system was still developing in Mashonaland West province. Lastly, neonatal deaths are rare, necessitating a larger sample size for effective evaluation.

## CONCLUSION

This comprehensive analysis provides robust evidence for targeting interventions to reduce preventable neonatal deaths in Zimbabwe. The multilevel modelling approach, combined with machine learning techniques, offered new insights into the complex determinants of neonatal deaths. By addressing risk factors at individual, household, and community levels, significant reductions in neonatal mortality can be achieved.

The results underscore the importance of both clinical and community health system strengthening interventions. Implementing the recommended interventions on strengthening antenatal care, birth spacing interventions, integrated health system approach (strengthening VHWs programs, enhancing facility community linkages) and institutionalizing community health system) has the potential to accelerate progress toward Zimbabwe's neonatal mortality reduction.

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**Author Contributions**

MG led the research process, data collection, analysis, and manuscript writing, ensuring accuracy and relevance. PC supported data analysis and manuscript review, while KB provided valuable feedback on research design and interpretation. CD assisted with ethical approvals and manuscript review. EK collaborated on design and co-authored the manuscript, focusing on findings and implications.

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