Foot-and-Mouth Disease Reporting in High-Risk Regions: Performance and Perceptions in the Hindu Kush Sub-Regions of Pakistan

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Abstract

In surveillance systems, disease reporting is crucial, especially for detecting new diseases. Comprehensive and continuous monitoring reduces the time for disease detection and limits its spread. In the Hindu Kush sub-regions of Pakistan—encompassing Bajaur, Mohmand, and Khyber—exotic diseases such as sheep and goat pox, lumpy skin disease, peste des petits ruminants, and foot and mouth disease have historically been introduced. However, several factors can impede disease reporting sensitivity across diverse production systems. Robust and efficient disease reporting systems are crucial for animal health services. In this context, we describe a training exercise aimed at enhancing the knowledge and skills of animal health services in these three districts. Additionally, we evaluate the sensitivity of foot and mouth disease reporting in the Hindu Kush sub-regions, identifying gaps and constraints. Through consultations with official veterinarians and scenario tree modeling, we found variations in reporting sensitivity between central and local veterinary authorities. Factors such as clinical awareness, reporting procedures, and biosecurity measures significantly influence early disease reporting, particularly in sectors with lower reporting sensitivity (e.g., small ruminant herds, mixed bovine herds, and backyard herds). Despite limitations, this training exercise provides an effective framework to strengthen veterinary capacities and offer initial evidence for targeted interventions, ultimately mitigating the risk of disease introduction.

Keywords: disease reporting, FMD, training exercise, veterinary authorities

I. INTRODUCTION

A rapid and cost-effective management of livestock diseases requires early detection of new outbreaks. For fast-spreading TADs such as FMD, this is especially crucial [1]. FMD is a highly infectious disease that affects livestock with split hooves, such as cattle, sheep, goats, pigs and wild animals [2]. FMD outbreaks can cause huge economic losses in disease-free areas or regions, because of lower productivity and higher control costs [3]. Losing market access can be very costly for countries that export livestock products [3]. Countries that are free of FMD try to reduce the risk of introducing and spreading the disease [4]. Despite efforts, complete prevention remains elusive, and FMD outbreaks have incurred approximately $25 billion in costs over the past 15 years in countries that were previously disease-free [3].

The Hindu Kush is a mountain range that stretches across Afghanistan, Pakistan, India, China, and Tajikistan. It is home to diverse agro-ecological zones and livestock production systems [5]. FMD reporting systems serve as mechanisms for detecting, notifying, confirming, and recording FMD cases or outbreaks by relevant authorities. These systems can be either active or passive [6]. Active reporting entails systematic surveillance to collect data on FMD occurrence and risk factors [7]. Observers or farmers report suspected FMD cases voluntarily through passive reporting [8]. Farmers' performance and perceptions regarding FMD reporting systems significantly impact the effectiveness and efficiency of FMD control and prevention strategies [9]. These perceptions can be influenced by factors such as awareness, access, incentives, trust, communication, and feedback [10]. Active surveillance, aimed at monitoring disease occurrence in a population or specific area, demands consistent and rigorous efforts [11]. In contrast, passive reporting constitutes an essential component of animal health surveillance, relying on voluntary reports from observers regarding suspected disease cases [12]. This form of animal health surveillance relies on a network of stakeholders, including animal health professionals, para-professionals, animal owners, producers, and processors within the livestock industry. Their role is to diligently observe and report clinical signs of disease in animals [13]. While this approach may have limitations in terms of providing fully representative information on populations, when implemented effectively, it can provide continuous and comprehensive coverage. Moreover, it serves as a highly effective method for detecting new and emerging diseases [14]. Veterinary disease reporting systems operate as sequential mechanisms, requiring a series of events to unfold before animal health authorities become aware of a disease outbreak [15]. The effectiveness of these systems primarily hinges on their sensitivity—the likelihood that an exotic or emerging disease outbreak will be promptly detected by the relevant authorities [16]. Given the pivotal role of passive reporting systems in early disease detection, it is crucial for animal health services to assess the sensitivity of their system. This assessment not only reveals any existing flaws but also provides a basis for targeted improvements and strategic investments.

In the years 2020-21, veterinarians from the animal health sector in Bajaur, Mohmand, and Khyber actively participated in a study and training initiative specifically tailored for the Hindu Kush sub-regions of Pakistan. The objectives of this intervention were threefold: (a) enhancing knowledge related to evaluating and characterizing disease reporting systems, particularly focusing on foot-and-mouth disease (FMD), (b) improving survey skills for assessing disease awareness and reporting attitudes, and © deepening the understanding of disease reporting sensitivity within the region. Our research paper introduces a comprehensive framework for data collection and skill development, along with preliminary findings on reporting sensitivity in the Hindu Kush sub-regions.

II. MATERIALS AND METHODS

A. STUDY AREA

The study area lies on the western border of Pakistan, along a north-to-south strip of hilly terrain [17] that forms the southwestern part of the Hindu Kush range. The area has dry arid to semi-arid weather conditions. The sub-regions of Bajaur (1290 sq. km), Mohmand (2296 sq. km), and Khyber (2576 sq. km) districts are shown in Figure 1, along with their topography. The Bajaur district lies on the northwest side, bordered by Dir and Malakand districts on the southeast, Afghanistan on the northwest, and Mohmand district on the southwest, it has seven tehsilsThe Mohmand district, with seven tehsils, lies in the north. It borders Bajaur and Khyber districts in the south, the Malakan protected area and Charsadda district in the east, the Peshawar district in the southeast, and Afghanistan in the west. The Khyber district is the most famous district in the former FATA boundary. It borders Peshawar City, the Orakzai and Kurram districts, and Afghanistan. It has three tehsils: Bara, Jamrud, and LandiKotel. (Figure 1)

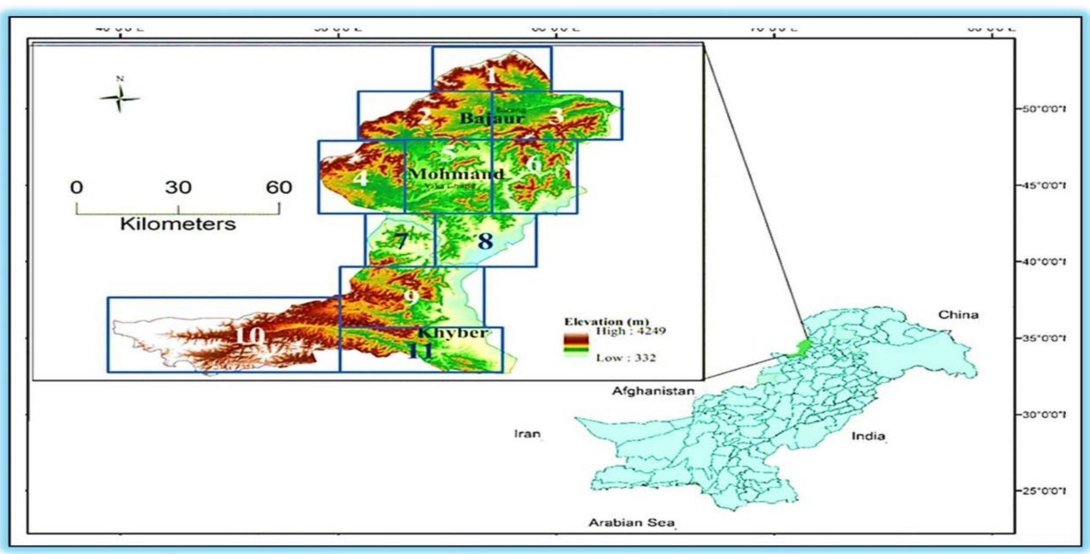


Figure 1 The rectangles on the study area distribution map show the Bajaur, Mohmand, and Khyber districts of Pakistan situated in the Hindu Kush region. These sub-regions are divided based on variability in precipitation.
The susceptible livestock species have different population sizes in the three District of the region (Table 1)

(Table 1 Populations of livestock per species in Pakistan's Bajour, Mohmand, Khyber Hindu Kush regions (2021)

Area	Cattle	Buffaloes	Sheep	Goat	Total
Bajour	283148	10312	58567	157948	509975
Mohmand	457710	19362	411011	681375	1569458
Khyber	114789	6060	64472	240597	425918
Overall Total	855647	35734	534050	1079920	2505351

B. Reporting diseases: assessing its effectiveness

Disease reporting plays a crucial role in detecting, monitoring, and controlling outbreaks of both infectious and noncommunicable diseases. Enhancing disease reporting in different regions requires context-specific strategies based on local resources and challenges. Evaluation methods can be quantitative or qualitative. However, the system's effectiveness is most accurately gauged by its sensitivity—the likelihood that an exotic or emerging disease outbreak will be noticed by animal health authorities once it has been introduced [18]. Typically, this assessment occurs after the disease has already spread. When no outbreaks occur, direct measurement of surveillance system sensitivity becomes challenging, necessitating alternative approaches such as modeling. [16]. There are four main steps that need to happen for a new disease to be reported to the animal health authorities [7]. The conditions for effective disease reporting include: (a) observable signs of illness in animals, (b) regular checks by the owner, (c) awareness that symptoms may be serious, and (d) prompt communication with a private or public veterinarian. W Viewing disease reporting systems as series-based mechanisms provides valuable insights into their functioning. In practice, a sequence of events must occur for animal health authorities to become aware of a disease outbreak [19]. In order to confirm the presence of a disease within a herd, the owner observes symptoms of illness in the animals. Recognizing the unusual nature of these symptoms, they promptly seek assistance from a veterinarian. A clinical examination ensues, during which the examiner identifies the significance of the disease and collects appropriate samples for laboratory testing. Upon proper testing, the lab confirms the positive results. The reporting chain involves a series of critical events that must occur for authorities to become informed about a disease [20]. A scenario tree, comprising six steps, can effectively illustrate this reporting process for the Hindu Kush sub-regions. (Figure 2).

C. The Elicitation of Expert Opinion

To address uncertainty arising from data limitations or infeasible data collection, we employed expert elicitation [21]. Specifically, we consulted veterinary authorities to assess the sensitivity of the disease reporting system across the three districts. Our approach involved creating a questionnaire to obtain estimates from official veterinarians regarding step probabilities within the reporting system for each district. Additionally, we compiled a list of herd types in the Hindu Kush region with input from relevant veterinary services (see Table 2). Experts provided a range of values—minimum, most likely, and maximum—for each herd type and step in the scenario tree model (depicted in Figure 2). We administered the questionnaire through face-to-face interactions, mobile channels, and online platforms, aiming to explore potential variations in views between central office and local veterinary officers regarding system performance.

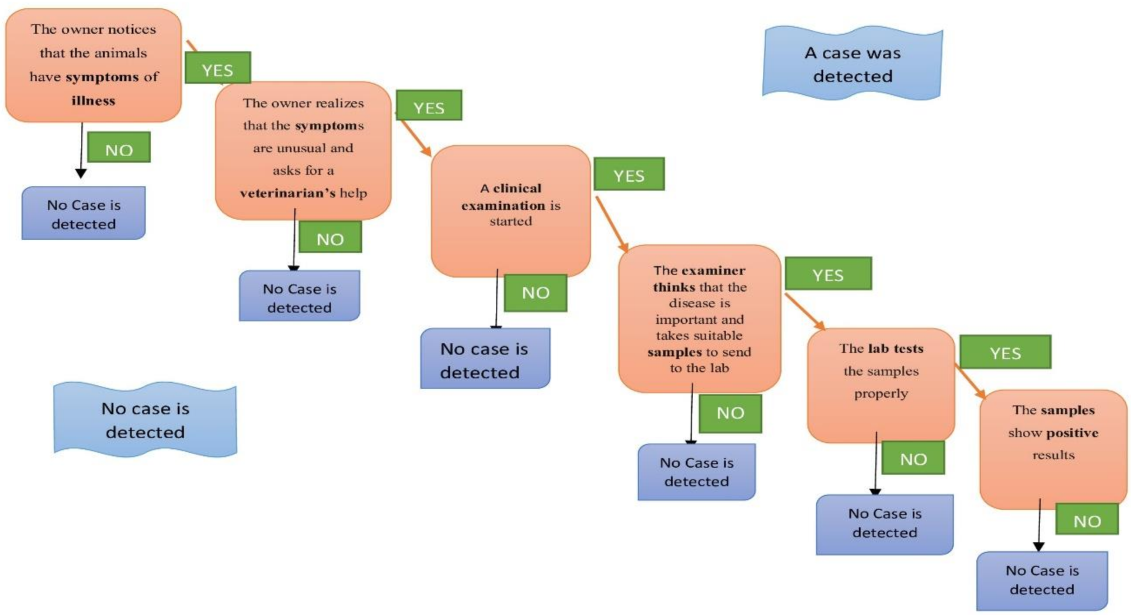


Figure 2

Scenario tree outlining the key steps for effective case detection in the disease reporting chain.

In the study area's three countries, only official veterinarians can declare a notifiable disease suspicion, following a clinical investigation and diagnostic sampling. The National Reference Laboratory then tests the samples to confirm or dismiss the suspicion.

D. The Purpose of This Workshop Was to Review the FMD Disease Reporting System for Livestock Owners by Local Authorities

The workshop focused on evaluating the Foot and Mouth Disease (FMD) reporting system for livestock owners in the Bajaur, Mohmand, and Khyber districts of Pakistan, situated within the Hindu Kush region. The primary objectives were to assess the current reporting mechanisms, identify challenges, enhance communication channels, foster collaboration among stakeholders, and provide targeted training and awareness sessions for livestock owners. By addressing these critical areas, the workshop aimed to improve the overall effectiveness of the FMD disease reporting system, contributing to better management and control of FMD outbreaks in these districts.

E. Designing and Delivering Livestock Owner Questionnaires

In the context of FMD awareness and reporting, direct data collection from livestock owners in the training area was essential. Designing and administering a questionnaire to livestock owners involves several critical steps to ensure accurate and relevant data. First, clear objectives must be defined, specifying the required information (e.g., disease prevalence, management practices, vaccination rates). The questionnaire should blend open-ended and closed-ended questions, maintaining clarity and alignment with objectives. Categories of inquiry may cover demographics, livestock management, health practices, disease management, and economic factors. Conducting a pilot test with a small group of livestock owners allows for adjustments based on question clarity and relevance before full implementation.

F. Data analysis

We presented the results of the expert elicitation exercise using a deterministic scenario tree model, relying on most likely estimates for step probabilities. To assess the sensitivity of the reporting systems, we applied the analytical modeling approach described earlier. The single herd sensitivity was then calculated based on the proportion of each herd type in the region. A pooled estimate weighted by the herd type in the Hindu Kush region is therefore presented. A combination of descriptive analytical approaches was the applied to summarize the collected data in each country. Histograms and bar charts were used to visualize the estimates of the reporting sensitivity by the central and local veterinary authorities in each country and by production system.

Table 2 Herd types, with descriptions of the main livestock production categories in the Hindu Kush region

S.no	Herd type	Species	Description	Bajour	Mohmand	Khyber
1	Dairy cattle herd	Bovine	Specialist milk producer; cattle are kept essentially to produce and sell milk	3	3	6
2	Commercial beef cattle herd	Bovine	Specialist beef production; cattle are kept to primarily produce and sell meat	2	4	7
3	Dairy and beef cattle herd	Bovine	Cattle are kept, usually in smaller herd sizes, to primarily produce and locally sell meat and/or milk on a smaller	8	7	11
4	Buffalo herd	Buffalo	Buffalo kept for milk	0	0	1
5	Commercial Small ruminants	Ovi caprine	Small ruminants are kept to primarily produce and sell meat/milk	52	37	42
6	Large-scale fattening Small ruminant herd	Small ruminant	Small ruminant are kept under intensive production system to be grown and sold for slaughter, for sheep/goat meat production	12	14	11
7	large-scale commercial breeding Sheep/goat	Sheep/goat	Sheep/goat are kept under intensive production system for producing replacement Sheep/goat to be sold to other holdings (e.g., fattening farms)	06	6	7
8	Small-scale commercial Sheep/goat	Sheep/goat	Sheep/goat are kept primarily to produce and sell meat on a smaller, local scale. Generally lower biosecurity than intensive systems	3	1	2
9	Backyard herd	Mixed	Small number of animals (cattle, buffalo, sheep, goat) kept primarily for own consumption (non-commercial)	14	28	13

III. RESULTS

A. Participation in Training and Surveys

The Veterinary Services in the three districts consistently engaged in developing skills related to characterizing and evaluating the disease reporting system within the study area. Each district nominated 12 official veterinarians from the Hindu Kush region—specifically from Bajaur, Mohmand, and Khyber—to participate in a face-to-face survey. Additionally, the same questionnaire was administered to 12 veterinarians from the local veterinary authorities in each district, with four veterinarians per district participating in a training course. This combined approach allowed for estimating the sensitivity of the disease reporting system by both central and local authorities. Subsequently, the 12 official local veterinarians (four from Bajaur, four from Mohmand, and four from Khyber) participated in a training workshop, alongside a representative from the central authorities of each district. Overall, 15 official veterinarians were selected by the participating districts based on defined criteria, and upon successful completion of the training, they took part in a face-to-face training workshop.

B. Predictable Probability of Detecting an FMD Outbreak

The results of the elicitation process were segregated by district and categorized based on central and local authorities. These results were then weighted to account for the proportion of different herd types in the Hindu Kush region (as shown in Table 2). In the event of Foot-and-Mouth Disease (FMD) occurring randomly in a single herd, the pooled estimated likelihood of it being reported and accurately diagnosed as FMD was 45%, 50%, and 75% by the central veterinary authorities of Bajaur, Mohmand, and Khyber, respectively (as indicated in Table 3). Notably, it would require 5, 4, and 2 infected herds in Bajaur, Mohmand, and Khyber, respectively, before authorities could express 95% confidence in detecting an outbreak. In contrast, the estimates from local veterinary authorities were 40%, 50%, and 20% in Bajaur, Mohmand, and Khyber, respectively, corresponding to 5, 4, and 15 herds being infected before authorities could confidently identify an outbreak.

C. Sensitivity of Reporting at Each Stage of the Scenario Tree

The scenario tree model revealed individual probabilities associated with six critical steps within the reporting chain for each district (as detailed in Tables 4 and Figure 4). In Bajaur, central veterinary authorities estimated that the least sensitive step was when livestock owners observed animals displaying clinical signs compatible with Foot-and-Mouth Disease (FMD) (Step 1), with a sensitivity of 70%. Conversely, in Mohmand, the least sensitive steps were identified as livestock owners recognizing the need for further veterinary assistance based on clinical signs (Step 2, sensitivity of 75%) and initiating a clinical investigation (Step 3, sensitivity of 78%). Local veterinary authorities in both Mohmand and Bajaur concurred that Step 2 (owners recognizing abnormal signs requiring veterinary assistance) was the least sensitive in the system (with sensitivities of 72% and 78%, respectively). However, in both districts, local official veterinarians considered the first three steps of the reporting chain to have approximately equivalent overall sensitivity (around 75%). In Khyber, Step 1 (livestock owners observing animals with clinical signs compatible with FMD) was estimated as the least sensitive (65%), followed by Step 2 (owners recognizing abnormal signs requiring further veterinary assistance) with a sensitivity of 80%

D. Herd Type Variability in Reporting Sensitivity

In the Hindu Kush region, individual probabilities of reporting for the nine distinct herd types were analyzed separately for each district (as detailed in Table 4 and Figure 3). Notably, both central and local veterinary authorities in Bajaur identified commercial small ruminant herds (Herd Type 5) as the least sensitive in reporting suspected Foot-and-Mouth Disease (FMD) cases. Similarly, in Mohmand, commercial small ruminant herds (Herd Type 5) were also considered the least sensitive. In contrast, Khyber district estimated that backyard mixed herds (Herd Type 9) had the lowest reporting sensitivity, according to both central and local authorities (as indicated in Table 4 and Figure 3). Furthermore, local veterinary authorities provided insights into reporting sensitivities per herd type. In Bajaur and Mohmand, commercial mixed dairy and beef cattle herds (Herd Type 3) were identified as the least sensitive. Meanwhile, in Khyber, backyard mixed herds (Herd Type 9) were once again estimated to be the least sensitive (as shown in Table 4). Additionally, Bajaur highlighted small-scale non-commercial sheep/goat herds (Herd Type 8) as among the least sensitive production systems, alongside commercial mixed dairy and beef cattle herds. Overall, the reporting probabilities by herd types, as perceived by local veterinary authorities, consistently fell below the estimates provided by central authorities across all three districts. This discrepancy suggests a perceived gap in the effectiveness of the disease reporting system at the local level, particularly concerning specific herd types.

Table 3 The expert elicitation results for single herd sensitivity and the number of herds required to have 95% confidence that the disease would be efficiently reported were estimated by both the local and central veterinary authorities.

Distract	Central Sensitivity (%)	Local Sensitivity (%)	Number of Herds for 95% Confidence (Central)	Number of Herds for 95% Confidence (Local)
Bajaur	45	40	5	5
Mohmand	50	50	4	4
Khyber	75	20	2	15

Table 4 Expert elicitation results. The herd types and the reporting steps within the scenario tree modeling, with the lowest sensitivity to disease reporting, were estimated by both the local and central veterinary authorities.

District	Central Herd Type with the Lowest Sensitivity	Local Herd Type with the Lowest Sensitivity	Central Scenario Tree Reporting Step with the Lowest Sensitivity	Local Scenario Tree Reporting Step with the Lowest Sensitivity
Bajaur	Herd type 5	Herd type 9	Step 1	Step 2
Mohmand	Herd type 9	Herd type 3,8	Step 2	Step 3
Khyber	Herd type 3	Herd type 9	Step 1	Step 1

Figure 3 Sensitivity of Disease Reporting by Herd Type

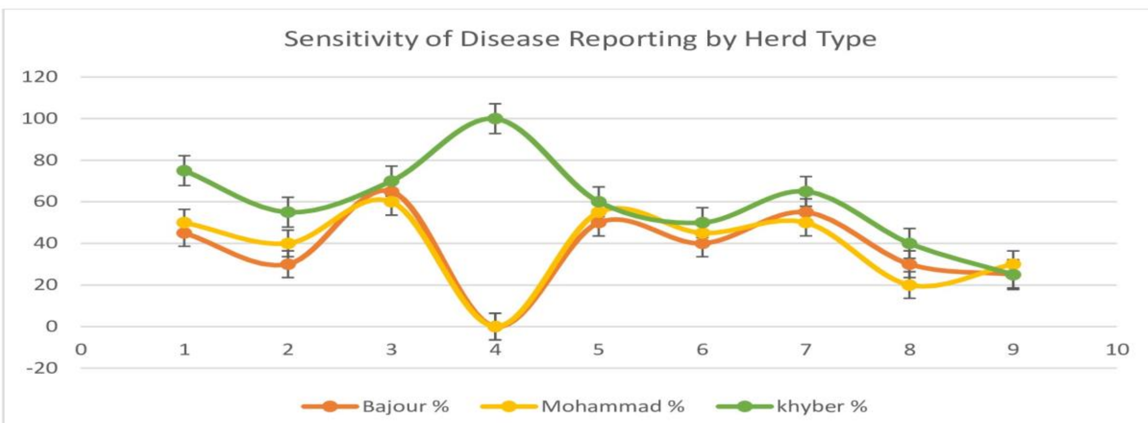
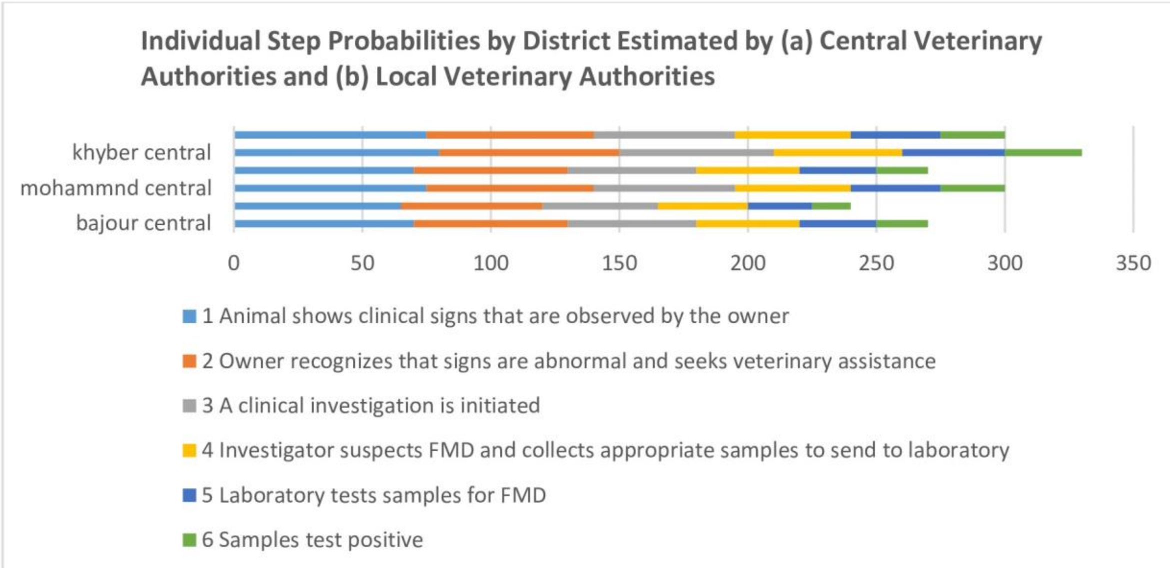


Figure 4 Individual Step Probabilities by District Estimated by (a) Central Veterinary Authorities and (b) Local Veterinary Authorities



E. Questionnaire for Livestock Owners

The local veterinarians participating at the training workshop designed and developed a questionnaire for investigating FMD awareness and attitudes to reporting by livestock owners. The four core elements of the questionnaire identified by the group work were:

1. farm background

2. awareness of clinical signs and knowledge of reporting procedures

3. motivations for reporting a suspicion of FMD

4. motivations for not reporting a suspicion

This survey was based on convenience sampling, particularly for proximity to the workshop location. The extent of bias associated with the small sample size and the lack of sampling frame did not allow for detailed statistical analysis. However, as part of the training, participants conducted in-class simple descriptive analyses. only 56% of the livestock owners interviewed could describe at least one clinical symptom associated with FMD, although all livestock owners interviewed had heard of the disease.

IV. DISCUSSION

Disease reporting plays a crucial role in surveillance systems, allowing early detection of new and emerging diseases worldwide, including major livestock-exporting countries [18, 22]. This surveillance approach offers comprehensive and continuous monitoring, as virtually all farmed herds are observed daily by livestock keepers or owners. Rapid reporting is essential—the time from disease onset to official notification directly impacts disease spread and economic consequences during an epidemic [23]. In the Hindu Kush sub-regions, historically, diseases like Foot-and-Mouth Disease (FMD), Lumpy Skin Disease (LSD), and Peste des Petits Ruminants (PPR) have rapidly spread across borders into Pakistan. Despite risk-based active surveillance programs, livestock owners and stakeholders (including hunters) remain the frontline for disease surveillance. Recognizing the pivotal role of disease reporting, animal health services must assess its effectiveness, identify weaknesses, and prioritize interventions. A study and training initiative involving official veterinarians from Bajaur, Mohmand, and Khyber in 2020-21 aimed to enhance disease reporting performance. Through hands-on training and data analysis, the sensitivity of the reporting system was evaluated, revealing key gaps. Disease reporting systems, represented by scenario tree models, allow quantitative assessment by estimating single-step probabilities [24]. Expert elicitation was employed to quantify step probabilities within the scenario tree model representing the Foot-and-Mouth Disease (FMD) reporting system in the Hindu Kush sub-regions. We systematically consulted experts from veterinary authorities across the three districts. As part of a multicounty training exercise, we chose a relatively straightforward approach to expert elicitation. Veterinary staff from both central and local veterinary services provided estimates using minimum, most likely, and maximum values. The single herd sensitivities for FMD aligned with values reported in other contexts [25]. Notably, weaknesses identified through this elicitation process in all three districts were primarily related to livestock owners not consistently observing animals with clinical signs (Step 1) or failing to recognize signs requiring veterinary assistance (Step 2). Despite the study's inherent limitations, it's important to highlight that only 56% of interviewed livestock owners could describe at least one clinical symptom associated with FMD. Thus, individual awareness and attitudes remain critical factors influencing the sensitivity of FMD surveillance systems in the Hindu Kush sub-regions. Similar observations have been noted in European settings for other livestock diseases such as Brucellosis, Bluetongue, and Bovine Tuberculosis [26]. Even if suspicions were reported to veterinary services, one country in the region expressed concerns about implementing thorough investigations. This highlights financial and structural constraints faced by local veterinary authorities, especially in remote areas, affecting disease detection effectiveness. Commercial small ruminant herds, mixed dairy and beef bovine herds, and backyard mixed herds were identified as the least sensitive for disease detection [27]. Factors contributing to this include the mild or subclinical symptomatology of Foot-and-Mouth Disease (FMD) in small ruminants, their higher population proportion compared to large ruminants, common semi-extensive production systems, and the presence of free-ranging wildlife. These findings emerged from a training exercise aimed at enhancing veterinary services' ability to review disease reporting systems and prioritize interventions. However, it's important to acknowledge the study's limitations, including the use of a simple approach to synthesizing expert opinions due to data scarcity [28]. More structured expert elicitation methods can address uncertainties by involving a multidisciplinary sample of experts [29]. Generally, structured elicitation processes are transparent, more likely to be balanced and comprehensive, and accounting for issues and problems inherent in seeking opinions (such as bias). Additional applications of expert elicitation processes in order to improve understanding of surveillance systems might also include the use of rubrics, a qualitative process to describe the adequacy of the surveillance system [30], therefore being complementary to quantitative approaches. In practice, however, resources, particularly financial and temporal, often limit or determine the extent of an expert elicitation procedure. Disease reporting involves individual behaviours, perceptions and motivations in addition to knowledge and awareness issues, particularly among the stakeholders involved in the early steps of the reporting chain (e.g., from livestock owners) [31], increasing the complexity of identifying reliable estimates of the steps sensitivity in the reporting system. As the training workshop was held in Mohmand, the findings on FMD awareness and attitudes to reporting by livestock owners are necessarily limited to the Mohmand context. In addition, the survey was based on convenience sampling and on a limited sample size, therefore, it cannot be considered representative of the Hindu Kush sub-regions as a whole. Nevertheless, it is worth noting that the main motivations for not reporting were fear of repercussions including culling of their animals, followed by the concern about creating a false alarm and lack of trust in the ability of the veterinary authorities to control the disease. These observations are consistent with other studies [32] and, to some extent, could relate with the impact on livestock owners of the recent incursions of exotic disease in the region, including LSD, and the control measures implemented (including animal culling). To enhance disease reporting, communication and training campaigns should focus on livestock owners and incorporate biosecurity practices within and between farms. Broader stakeholder involvement and emphasizing surveillance benefits can motivate reporting and build trust in institutions. While acknowledging study limitations, these findings can guide interventions to raise disease awareness and overcome reporting barriers. Targeted education programs for sectors with lower reporting sensitivity or higher introduction risk are cost-effective. Regular information sharing among relevant stakeholders (e.g., livestock owners, hunters) about notifiable diseases, like Foot-and-Mouth Disease (FMD), can improve communication. Strengthening veterinarians' communication skills fosters better reporting networks. Additionally, allocating resources to reduce risk—such as enhancing biosecurity at key herd types and farms—can mitigate disease spread.

V. CONCLUSIONS

In the Hindu Kush sub-regions of Pakistan—specifically Bajaur, Mohmand, and Khyber—disease reporting remains critical for detecting disease incursions. Understanding its effectiveness assists veterinary services in identifying weaknesses and allocating resources for system improvement. Our study and training exercise aimed to equip veterinarians from Bajaur, Mohmand, and Khyber with skills for assessing the reporting effectiveness of foot-and-mouth disease (FMD) and other TADs. By applying scenario tree modeling and expert elicitation, we quantified reporting system sensitivity. Interestingly, perceptions of reporting sensitivity differed between central and local veterinary authorities within the three Distract. While these findings are preliminary due to study limitations, they serve as a baseline for further assessments and provide initial evidence for targeted interventions. Strategies may involve educational programs for sectors with lower reporting sensitivity or higher introduction risks, along with innovative reporting tools to enhance detection sensitivity.

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