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Environmental Determinants of Landmine Detection by Dogs: Findings From a Large-scale Study in Afghanistan

This article's purpose is to examine the strengths and weaknesses of mine-detection dogs in different environments. The experiments employed a total of 39 dogs in Afghanistan between October 2002 and July 2003. The results are discussed here.

by Dr. Rebecca J. Sargisson [University of Waikato], Dr. Ian G. McLean [Consultant], Dr. Jennifer Brown [University of Canterbury] and Håvard Bach [Norwegian People's Aid]

Image 1. Dog, handler and supervisor; observer with camera in the background.
All photos courtesy of the authors.

Mine-detection dogs were first used during and after World War II and have been used with increasing frequency in Afghanistan since the first humanitarian mine-clearance operations began there in 1989.[1,2] Employing dogs to detect landmines and explosive remnants of war is comparable to the use of dogs to detect cryptic animal species, such as ground squirrels, which occur at low densities and tend to burrow underground.[3] Dogs may offer advantages over other methods of detection in these situations due to their ability to cover large land areas more quickly than other detection methods, while minimizing damage to fragile ecosystems.[4]

Given the long history of mine-detection dogs, it is reasonable to assume that the limitations on their use as mine detectors are thoroughly understood. Unfortunately, little research accompanied the original training and deployment of dogs as mine detectors. Essentially no published research existed on the principles underlying a dog's ability to detect mines before the Geneva International Centre for Humanitarian Demining began its work in 2000. Handicap International's 1998 review of the use of mine-detection dogs for humanitarian purposes appears to be the first significant review on the subject, and it concentrates primarily on operational issues.[5] In 1999, a meeting to discuss the use of dogs as mine detectors convened in Ljubljana, Slovenia, and the mine-dog community formally recognized the general absence of information for the first time.

Mines are routinely found in difficult and variable environmental situations. Therefore, the environmental influences on any detection technology should be understood and the constraints defined. Specifically, for any mine-clearance technology, it will be valuable to define the environmental conditions under which detection reliability declines or the limits beyond which the technology should not be used. This study was designed to sample the full range of conditions under which dogs are utilized in hot, dry, semi-desert environments in order to determine the ideal conditions in which to use dogs.

Mines were laid in an unused golf course near Kabul, Afghanistan. Dogs from the Mine Dog Centre were filmed while attempting to detect those mines using normal operating procedures. Weather conditions were recorded in the long-term and at the precise moment that a dog crossed a mine. These data enabled us to link detection success to context (season, vegetation) and weather (wind speed, temperature, humidity) during the search.

Method

Participants/subjects. A request for dogs was made through the Monitoring Evaluation Training Agency ahead of each proposed experimental trial, and the research team was normally assigned eight dogs and handlers and two supervisors for the period of the trial (one working week of six days).

A total of 39 dogs (22 male and 17 female) were used in the five trials. Of the 39 dogs, 28 were German Shepherds and 11 were Malinois (Belgian Shepherds). The average operational experience was 3.4 years (s.d. = 1.7). The average number of strips searched by one dog was 3.8 (s.d. = 1.9, range 1-11). "Strips" are defined below.

None of the 39 dogs shared a handler. All handlers were male with an average operational experience of 5.4 years (s.d. = 3.9).

One dog, Axel, was used in October 2002 and July 2003 (when four dogs were employed for the entire trial); this dog searched an unusually high number of strips (11). All other dogs were used for one trial only.

During operational search in Afghanistan, a handler and dog work closely with a supervisor who observes the search and monitors details such as ground missed by the dog (see Image 1). This practice allows the handler to concentrate on the details of the dog's search behavior, while the supervisor has a broader view to ensure complete coverage of ground and safety.[6] The experimental trials employed the same practice.

The researchers supplied two teams, between two and four people each. The observer used a video camera to record the dog throughout the search and verbalized details of the search into a microphone connected to the camera (see Image 1). The datum recorder ensured that weather data were noted when the dog crossed a mine (see Image 2).

Thus, at any one time during a trial, two pairs of teams worked: a **dog team** consisting of dog, handler and supervisor; and a **research team** consisting of observer and datum recorder(s) (see Images 1 and 2).

Image 2. Datum recorders with portable weather station (the temperature gauge is shaded by the box).

Image 3. The Kharga site showing an old pond (center right), a demining clearance site (center left) and the old golf-course clubhouse. Kharga dam in the background.

Mine	Origin	Explosive	Weight of explosives	Weight of mine
P4AP	Pakistan	Tetryl	30 g	140 g
Type 72 AP	China	TNT	50 g	140 g
YM1		RDX	50 g	190 g
PMN2	State factories	TNT/RDX	100 g	420 g
PMN	State factories	TNT	240 g	550 g
P3AT	Pakistan	TNT	5 kg	7 kg
TC-6	Italy, various	TNT/RDX	6 kg	8.4 kg
TM57	State factories	various	6.3 kg	8.5 kg

Table 1. Mine types, names and sizes used in the Kharga test field.[7]

The site. The test field was established in a steep-sided valley at Kharga, 15 km north of Kabul just below a reservoir dam (see Image 3). The site was originally established as a nine-hole golf course as part of a larger recreational and commercial development. In previous history, it was a battlefield. When GICHD first visited the site in 2001, a crater from a large bomb was in the middle of the site, some artillery pieces were stored on site and most of the buildings were destroyed.

Prior to establishment as a research minefield, the site was searched using MDC's dogs. The dogs found some explosive items; a large number of indications at which nothing was found suggested that considerable explosive contamination occurred on-site. Battlefield clearance was conducted in the hills surrounding the site during early 2003.

Up to 30 cm. of topsoil was therefore removed from about two-thirds of the site prior to the test mines being laid, with the aim of removing most of the contamination left by the partially exploded bomb. After topsoil removal, the site was cleared using dogs, and the indication rate was considerably reduced. Although not ideal for the trials, the site was realistic, because dogs routinely work in highly contaminated situations in Afghanistan. The MDC training area in Kabul where the dogs are trained is also a highly contaminated site.

Mine type	0	7.5	15	20	25
P4AP	0	1	3	0	2
Type 72 AP	4	4	8	4	4
YM1	0	4	4	0	4
PMN2	4	4	4	0	0
PMN	4	4	4	4	4
P3AT	4	4	4	4	0
TC-6	4	4	4	0	0
TM57	0	4	4	0	4

Table 2. Number of mines of each type laid at each depth in the Kharga test field.

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Image 4. Method of defining a quadrant for vegetation sampling. A surface-laid mine is in the center of the one square-meter quadrant.

Site preparation. After soil preparation, the site was laid out into 31 strips, each 40 m x 8 m. The length of 40 m provided a realistic search baseline, and the width of 8 m was the standard line search distance for Afghanistan dogs.

Test mines were laid in March and May 2002. Table 1 (page 75) gives details of the mine types. Using eight mine types, a total of 114 mines were laid at five different depths (as shown in Table 2 on page 75). The number of mines in a strip was randomly assigned using a weighted mean (average of four per strip) and restricted range (minimum 2, maximum 5). Once a mine was assigned to a strip, location within the strip was assigned randomly with the limitations that a mine was a minimum of 3 m from any other mine and 0.5 m from any boundary. Having randomly defined 120 locations in 30 strips (one strip was left empty), mine x depth combinations were then randomly assigned to each location in replicates of 4 (this is a total of 30 mine x depth assignments for 120 locations).

Mines were laid following strict International Mine Action Standards protocols, involving washing and sterilizing the mines three times over several days.[8] All handling and digging tools were sterilized in boiling water. Once sterilized, mines were handled with plastic gloves. All soil not returned to a hole was removed completely from the site.

After completion of the study, all mines were dug up to ensure that they were still in position. All were in place except one, which was displaced 0.5 m from its assigned location. Whether this discrepancy was an error in original placement or the mine had shifted after burial is uncertain. However, the mine was considered close enough to the assigned position for data associated with that mine to be used normally.

Apparatus. Portable weather stations were set up (see Image 2, page 75) to record weather variables during the dog searches. Equipment was used to record temperature in the soil's surface layer, temperature at ground level in exposed sun, temperature in shade at chest height, relative humidity in shade at chest height, soil-moisture content (based on conductance), mean wind speed over 20 sec (m/s) and peak wind speed over 20 sec (m/s).

Digital video cameras were placed on tripods and positioned to capture the dog's searching behavior. Additionally, microphones clipped to the camera operator's clothing allowed voice recording of observed behavior, including notification of the dog crossing a mine. Cross referencing between observer (on tape) and datum recorder (on paper) was achieved using coordinated time records. The observer and the datum recorder also held a mapped layout of each trial strip to ensure that weather records, dog behavior and mine position could be linked.

Measuring tapes were used to measure the distance from a dog's indication to the site of the buried mine. A knotted rope defined a 1-sq. m. quadrant around the mine in order to measure vegetation (see Image 4).

Procedure

The research team arrived at a strip before the dog team. The camera was positioned at an angle to the predicted search direction (determined from wind direction). A small portable weather station (a shaded stand, Image 2) was placed about 15 m from the strip. When the dog team arrived, they established a search direction and went to work.

Search direction was frequently adjusted as the wind changed. The observer and camera were moved as necessary to ensure an appropriate camera angle and lighting.

The weather recorder took records every four minutes or immediately if the dog crossed a mine at a moment when no data were being recorded. About two minutes were required to make a full set of weather records. The dog always worked across the wind, and down wind and search direction was adjusted frequently, so wind direction was not recorded.

When the dog gave an indication, the supervisor marked the site with a flag or rock, and then the dog continued to search. The indication was recorded on a map of the strip with a time and number in order to ensure that it could be linked to the weather records and video. A time and number were also noted if a mine was missed.

The distance between the mine and the indication marker was recorded, up to 2 m. Distances greater than 2 m to a mine were ignored, and the indication was treated as a false alarm (a false alarm is the same as a false positive).

In most cases, the dog searched the entire strip in one sequence. A complete search of a strip required between 16 and 77 minutes of search time (mean = 42, s.d. = 14). The time required to search a strip in Trial 2 (April 2003) was significantly longer (mean = 55 min.; $F(1, 4) = 16.86$, $p < .001$) than in any other trial (mean range 33 to 40 min for the other four trials). After completing the search of a strip, the dog team left the trial area, returning about 30 minutes later to search the next strip. Once the dog team had left, the datum recorders moved into the strip to measure the distance from the dog's indications to the mines and to measure vegetation cover around the mines. Total vegetation cover was measured on a 4-point scale: 0–25%, 25–50%, 50–75%, 75–100%. Cover was viewed as any vegetation that could be a barrier between the dog's nose and the ground, and thus included all dead vegetation. The presence of spiky or aromatic plants was measured separately on 4-point scales: 0=absent, 1=present, 2=common and 3=dominant.

Data Analysis

All mines having an indication within 2 m were treated as found mines in the analyses. Detection success was calculated as a logit transform of proportion of mines found. Specifically, detection success is shown as logit *p*, which is calculated as $\text{logit } p = \log_{10}(p / (1 - p))$, where *p* = proportion found (found mines/(found + missed mines)). Logit *p* has the advantage of being an equal-interval scale and is not bounded by upper and lower limits, as is proportion found, enabling the use of parametric statistical analyses. In the situation in which proportion found was 1.0 (indicating zero misses), misses were recorded as 0.25 in order to avoid an infinite logit *p*. Higher values of logit *p* reflect higher detection success, much in the same way as proportion correct. If 99% of the available mines were detected, logit *p* would be two, while a 50% find rate would result in a logit *p* value of zero. A find rate less than 50% produces negative logit *p* values, and the larger the negative number, the poorer the detection success.

Image 5. Weather station with dog and research teams working in the background.

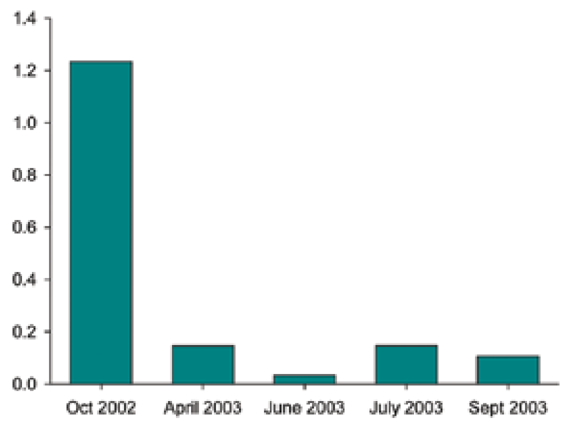

Figure 1. Mean detection success (logit p) calculated across dogs for each trial.

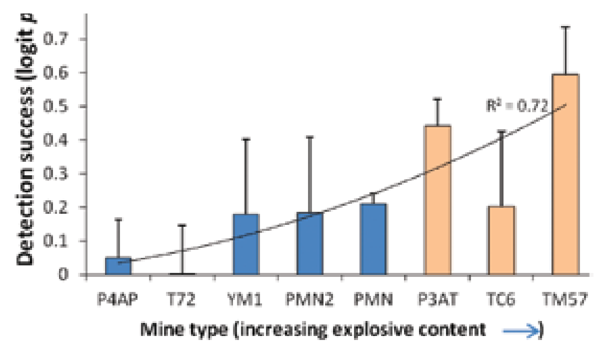

Figure 3. Mean detection success (logit *p*) calculated across trials for each mine type. Anti-personnel mines are shown in blue, and anti-tank mines in orange. A polynomial curve was fitted to the data, and error bars represent the mean's standard error.

Detection success under different weather conditions. Mean detection success (logit *p*) differed significantly across the five trials according to a one-way analysis of variance using the success scores for individual dogs (F(4, 36) = 3.41, *p* = .018). Detection success was significantly higher in October 2002 (mean = 1.23) than for any other trial and was lowest in June 2003 (mean = 0.03), although the other four trials did not significantly differ from each other (Fisher's LSD post-hoc test) (see Figure 1). Kabul experienced heavy rains in the spring of 2003, and the increased humidity and soil moisture appear to have hampered the dogs' ability to detect mines, as rainfall occurred immediately prior to the April and June trials (see Figure 2). The false-alarm rate was lowest in October 2002 and rose to higher and similar levels in all subsequent trials, supporting the hypothesis that heavy rains hampered detection success.

Informal observations suggested that the heavy spring rains may have distributed mine odor around the site, particularly along drainage channels running through the strips. Chemical analysis of soil samples supported this conclusion.[9]

The detection success achieved in October 2002 is most representative of drought conditions. Given the rarity of rain in Afghanistan before spring 2003, the dogs were unfamiliar with wet soils or working conditions, and detection success seemingly decreased as a result of rainfall immediately prior to the trials. Therefore, training of mine-detection dogs should include the full range of environmental conditions that may be encountered (even if that requires simulation of unusual conditions) or that mine-detection agencies withdraw dogs for retraining and licensing when unusual weather patterns occur. This precautionary approach may be particularly necessary when dogs move from dry to wet conditions (and not the reverse).

Mine type and depth. The proportion of each mine type found for each trial was converted to logit *p* and averaged across all trials (see Figure 3). Detection success was significantly positively correlated with weight of explosive (*r* = .38, *p* = .02), showing that detection success improved with the increasing size of mine. Type 72 anti-personnel mine (see Table 1) was the most difficult to find, and TM57 the easiest. Although a one-way analysis of variance showed no significant variation in detection success for the different mine types (*F*(7, 32) = 1.47, *p* = .21), a Fisher's LSD post-hoc test[10] showed that P4AP (*p* = .01) and T72 (*p* = .02) mines were significantly harder to find than TM57 mines.

Detection success varied significantly with mine depth (one-way analysis of variance (*F*(4, 20) = 2.97, *p* = .04) and was significantly negatively correlated with mine depth (*r* = -.39, *p* = .008). Thus, detection success decreased as depth increased, although with exceptions: The small T72 mines were poorly detected at all depths; for small YM1 mines, detection was poorest at the shallowest depth (7.5 cm); and the large TM57 mines were detected more successfully at deeper depths. The overall mean in Figure 4 represents the mean of all mine types at all mine depths and shows most clearly the decrease in detection success as a function of mine depth.

Vegetation. A significant effect of the amount of vegetation cover on detection success was found (*F*(3, 16) = 5.28, *p* = .01), with detection success decreasing with increasing vegetation cover near the mine

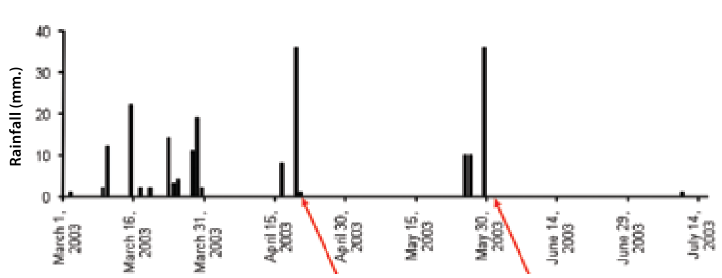

Figure 2. Rainfall (mm) at the Kargha field site in spring and summer of 2003. Arrows mark the first day of the April and June field trials.

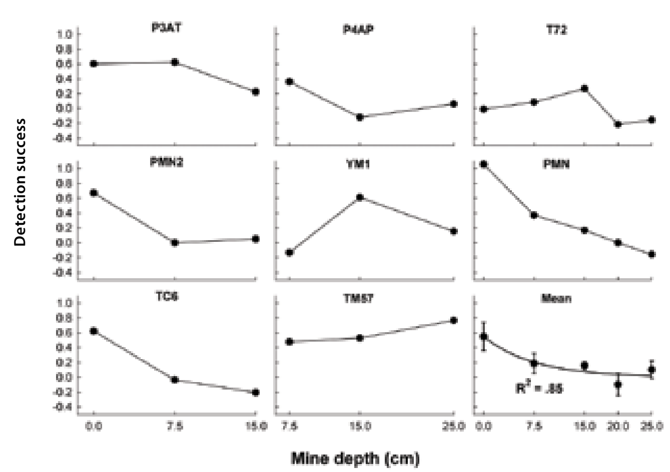

Figure 4. Mean detection success (logit *p*) for each mine type at each depth and for the mean across all mines at all depths. For the overall mean figure, an exponential decay function was fitted to the data, and error bars represent the standard error of the mean. Note that three possible X-axis scales are shown which reflect the fact that different mine types were laid at different depths (P3AT, PMN2 and TC6 at 0, 7.5 and 16 cm; P4AP, YM1 and TM57 at 7.5, 15 and 25 cm; and T72 and PMN at all five depths. (See Table 2.) The mean graph shows all data for all mine types for the depths at which they were available.

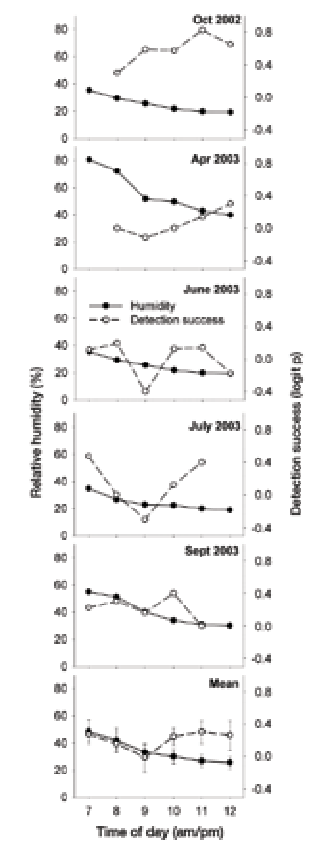

Figure 5. Relative humidity (%; filled circles) and detection success (logit *p*; open circles) plotted for each month against time of day (e.g., 7 represents 7 a.m.). The final graph is the mean of all five trials, and standard error bars represent standard error of the mean of the five trials.

(*r* = -.65, *p* = .002; mean logit *p* = 0.32, 0.23, 0.11, -0.33 for 0–25%, 25–50%, 50–75% and 75–100% vegetation cover in the 1-sq m quadrant around the mine). The spikiness of plants surrounding the mine had no significant effect on detection success (*F*(3, 16) = 0.44, *p* = .72), with a correlation revealing a negative but nonsignificant, relationship (*r* = -.13, *p* = .59). The strength of plant aromas surrounding the mine also had no effect on detection success (*F*(3, 16) = 0.02, *p* = .996), with no correlation found between these two variables (*r* = -.009, *p* = .99).

Weather variables. A principal component analysis identified humidity as contributing the most explanatory power to the data, in that detection success was poorer in high humidity. However, when humidity was included in a logistic-regression analysis involving month, mine type and depth, humidity did not explain significantly more variance than was already explained by month. However, Figure 10 shows that, for most months, humidity rarely varied. For October 2002, June 2003 and July 2003, relative humidity rarely climbed higher than 30%. The greatest variability in humidity occurred in April 2003, and its implications are discussed below.

Overall, none of the microvariation in environmental variables measured at the time a dog crossed a mine affected the probability of that mine's discovery. We conclude that the probability of dogs finding mines was robust with respect to the environmental variation normally experienced by dogs in Afghanistan. Despite the possible effects of humidity discussed below, in general terms, dogs worked with similar effectiveness under all typical working conditions.

Detection success across the working day. Some evidence, shown in Figure 5, indicates that detection success was occasionally higher in the early morning, dropping across the morning and increasing again at midday. As shown in Figure 5, this pattern particularly occurred for the trials conducted in April 2003, June 2003 and July 2003. The mean data clearly show that detection success decreased simultaneously with humidity until 9 a.m. However, after 9 a.m., humidity continued to decrease, whereas detection success increased. We suspect that, if greater variability in humidity was encountered during more trials (and not just for April 2003), the effect of humidity on detection success would have been stronger than that reported here.

We believe that two effects are operating here, as described by Phelan and Webb.[11]

- First, overnight dew wets the surface of the soil and displaces surface odor. Little air movement happens overnight, thus displaced odor tends to concentrate immediately on and above the ground. When the sun first hits the ground (the time at which the dogs begin work), evaporation of surface moisture and overnight accumulation of odor together provide an increased concentration of mine odor near the ground surface for a short period (probably 20 minutes to 1 hour, depending on local conditions). Therefore the dogs detected the mines relatively easy in the early morning, giving the initially high detection rate.
- Second, as the soil surface warms up and convection disperses the overnight accumulation of dew, humidity begins interacting antagonistically with detection success. Relatively high humidity makes detection difficult, and detection improves as relative humidity declines through the morning. This effect is predicted because, when sniffing, the dog rapidly alternates exhalation and inhalation of moist air over the ground surface. This moist air displaces mine-odor molecules attached to surface dust into the vapor, allowing inhalation. When humidity is high, the process is less effective than with low humidity, because the key factor influencing odor-molecule release is the high moisture content of the dog's exhaled breath.

The lesson from these results on detection success through the morning suggests that some micromanagement of dog searching could improve overall detection success in arid environments. Specifically for the conditions experienced near Kabul, on calm mornings, dogs should take a break during the second hour after dawn, which is the period when detection success is predicted to be lowest as a result of humidity effects.

The reality is that use of dogs in arid environments is routinely limited by high temperatures later in the day, and mid-morning is a desirable time of day to be working dogs. It may not be realistic to stand dogs down for part of the morning.

Fortunately, there are other options. For example, maintenance training could include humidity management (such as spraying of water on training fields) in order to mimic the relatively difficult high humidity conditions experienced during mid-morning, and/or maintenance training could be focused on that part of the day at which humidity is highest in the operational theatre.

We encourage monitoring of relative humidity through the day in any operational theatre in which dogs are being used, but particularly in arid environments. Further, regular maintenance training should be conducted under the most challenging conditions likely to be experienced by the dogs—in general terms, meaning that part of the day when relative humidity is highest.

An issue that arose in this study was the distribution of odor as a result of heavy rainfall in arid environments. Odor of mines was clearly transferred downstream in runoff channels, resulting in detection of individual mines by dogs at distances well outside the standard clearance perimeter for manual demining. While the mine itself should still be found, the consequence is numerous, apparently false indications. Recognition of this effect may help to improve the efficiency of use of demining resources in operational situations.

Summary

The overall aim of this study was to explore the effects of environmental variables on mine detection by dogs working in Afghanistan. Data were gathered during five trials carried out in October 2002 and April, June, July and September 2003. Detection success was highest in October. After the October trial, Afghanistan experienced heavy rains, which appeared to lower detection success. No significant variation was apparent in detection success of the different mine types, although mines with higher explosive content (weight) were detected more easily than smaller mines. Detection success decreased with increasing mine depth. Higher levels of vegetation reduced detection success, but the presence of spiky or aromatic plants did not affect detection. While standard weather variables (temperature, relative humidity, wind speed) had no overall significant effects on detection success, humidity appeared to be the most important variable. Evidence indicated that high humidity results in poorer detection (in arid environments), except in the early morning, when dew on the ground's surface appeared to facilitate detection.

A key implication arising from this research is that relative humidity should be monitored in any operational theatre in which dogs are used, particularly in environments where humidity varies considerably through the day. Variation in humidity appeared to influence detection success, and this effect could be dealt with by either standing dogs down when humidity is high, or by undertaking maintenance training under the most challenging humidity conditions experienced in the operational theatre.

Odor was clearly conducted downstream from mines during severe rainfall events in the arid environment in which this study was undertaken, resulting in numerous apparently false indications in drainage channels. Understanding this phenomenon could result in more efficient use of clearance resources in operational situations.

See endnotes page 83

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Endnotes

Unplanned Explosions at Munitions Sites: Concerns and Consequences by Berman and Reina [from page 4]

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2. See, for example: "Mystery Surrounding the Turkmenistan Weapons Depot Explosion." Hvnews, 18 July 2011. *Hypervocal*. http://bit.ly/pEoP2s. Accessed 3 May 2012.
3. NAMSA provided funding through its Partnership for Peace Trust Fund projects in nine countries: Afghanistan, Albania, Azerbaijan, Georgia, Jordan, Mauritania, Moldova, Ukraine and Uzbekistan. Scott Willason, interview with author, 17 January 2012.
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