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Original Article

# Low-Oxygen Atmosphere and its Predictors among Agricultural Shallow Wells in Northern Thailand

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ABSTRACT

*Background:* In 2006, three farmers died at the bottom of an agricultural shallow well where the atmosphere contained only 6% oxygen. This study aimed to document the variability of levels of oxygen and selected hazardous gases in the atmosphere of wells, and to identify ambient conditions associated with the low-oxygen situation.
*Methods:* A cross-sectional survey, conducted in June 2007 and July 2007, measured the levels of oxygen, carbon monoxide, hydrogen sulfide, and explosive gas (percentage of lower explosive limit) at different depths of the atmosphere inside 253 wells in Kamphaengphet and Phitsanulok provinces. Ambient conditions and well use by farmers were recorded. Carbon dioxide was measured in a subset of wells. Variables independently associated with low-oxygen condition (<19.5%) were identified using multivariate logistic regression.
*Results:* One in five agricultural shallow wells had a low-oxygen status, with oxygen concentration decreasing with increasing depth within the well. The deepest-depth oxygen reading ranged from 0.0% to 20.9%. Low levels of other hazardous gases were detected in a small number of wells. The low-oxygen status was independently associated with the depth of the atmosphere column to the water surface [odds ratio (OR) = 13.5 for 8–11 m vs. <6 m], depth of water (OR = 0.17 for 3–<8 m vs. 0–1 m), well cover (OR = 3.95), time elapsed since the last rainfall (OR = 7.44 for >2 days vs. <1 day), and location of well in sandy soil (OR = 3.72). Among 11 wells tested, carbon dioxide was detected in high concentration (>25,000 ppm) in seven wells with a low oxygen level.
*Conclusion:* Oxygen concentrations in the wells vary widely even within a small area and decrease with increasing depth.


## 1. Introduction

Persons entering confined spaces are at risk of a variety of health hazards. These hazards stem from the restricted volume of space inside such spaces and the small dimensions of the opening to the outside environment, with consequent difficulty in obtaining access to and exiting from the space, or a combination of the two. These features readily predispose those entering a confined space to exposure to changes in the atmospheric composition within that space, which may be harmful to their health. Confined spaces are most commonly encountered in work situations, and include sewers, casings, tanks, silos, vaults, tunnels, and compartments of ships [1–4].

A common atmospheric change occurring in confined spaces may involve a reduction in the volume percent of oxygen, as a result of oxygen-consuming reactions within the space, replacement of oxygen by other gases, or build-up of toxic gases. Persons entering a confined space may be incapacitated or may even die as a result of these atmospheric changes. While normal atmosphere close to earth contains 20.9% of oxygen by volume, the Occupational Safety and Health Administration regulation and many confined-space guidance documents indicate that an atmospheric oxygen concentration of 19.5% is the lowest level acceptable for entry into such spaces [2,3].

The problems of adverse effects on the health of a person inside a confined space are frequently compounded by the difficulty of

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making a rapid exit, the difficulty faced by rescuers in gaining entry, and the hindrances to communication between inside and outside of the space.

A number of investigation reports have given data on fatalities in confined spaces. In the United States of America, the Division of Safety Research of the National Institute for Occupational Safety and Health is currently conducting the Fatal Accident Circumstances and Epidemiology project, which focuses primarily on selected electrical- and confined space-related fatalities [5,6]. Suruda et al. [7] analyzed data from the National Traumatic Occupational Fatalities surveillance system, which the National Institute for Occupational Safety and Health had assembled. During the 10-year period between 1980 and 1989, 585 separate fatal incidents occurred in confined spaces, claiming 670 victims. Seventy-two (12%) of the fatal incidents involved multiple victims.

In Thailand, cases of death in confined space occur almost every year. Between 2004 and 2008, there were eight investigation reports of 34 deaths and injuries in confined spaces [8]. An estimated 60% of the fatalities involved would-be rescuers. These rescuers had tried to help someone who had collapsed, but presumably had not given due consideration to the reason for the collapse. In one event, in 2006, three farmers died in a shallow well in a field in Kamphaengphet province, northern Thailand. According to the investigation report, local health officers who measured the gas content of the atmosphere at the bottom of the well 6 days later found the oxygen level to be only 5.9% [9]. The Bureau of Occupational and Environmental Diseases, Ministry of Public Health, then measured oxygen levels in 57 other shallow wells in the same region and found that 16% had low levels of oxygen (0.3–16%), which would have posed a hazard to anyone entering them, although toxic gases were not detected in any of the wells [10]. It was reported that the wells were used as a source of irrigation water for paddy fields, and farmers claimed that they had to enter the wells from time to time to set up the pumping system and to carry out general maintenance (Fig. 1).

While irrigation wells are a common feature of the rural landscape in the lower north of Thailand, the survey in Kamphaengphet province [10] made no mention of why some wells presented hazardous conditions while others in the same locality did not. An understanding of the factors predisposing to hazardous conditions in shallow wells would be useful in identifying unsafe wells, and possibly in identifying ways to remediate the condition of hazardous wells. Such understanding may enable the formulation of practical recommendations or guidelines for the safe use and management of shallow wells, for dissemination among farmers and other well users.

This study was therefore conducted with the aim of documenting the variability in oxygen content and occurrence of selected hazardous gases in the atmosphere within shallow wells in the lower north of Thailand, and identifying the ambient conditions—well-construction material and design, frequency of water use, climate, and surroundings—that could predict the low-oxygen condition.

## 2. Materials and methods

A cross-sectional study of shallow agricultural wells in five villages in Kamphaengphet and Phitsanulok provinces, in the lower north of Thailand, was undertaken. Three villages were selected from Kamphaengphet province where the recent fatalities occurred. Two villages were selected from Phitsanulok province based on similarity of agricultural practices to those of the Kamphaengphet villages. Phitsanulok province borders Kamphaengphet province, and the two provinces are similar in that both have many shallow wells that are used for rice-field irrigation.

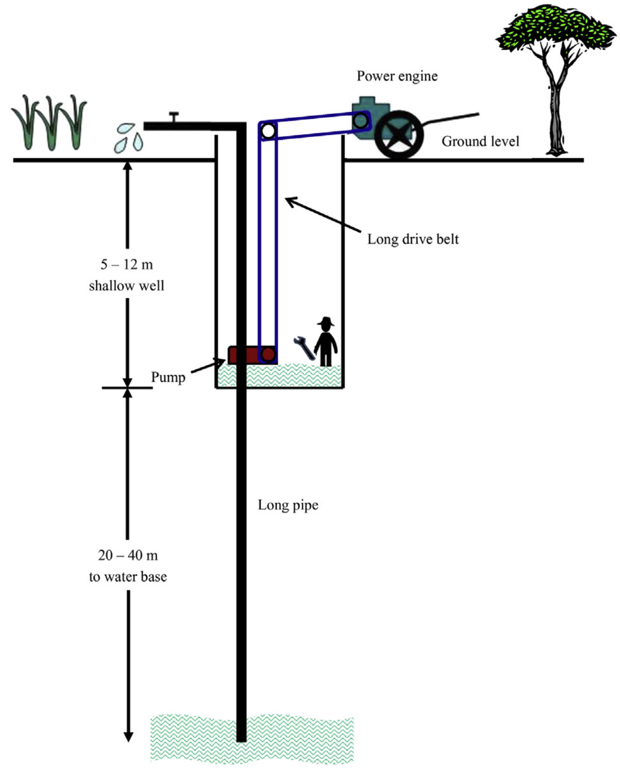


**Fig. 1.** Typical design of an agricultural shallow well in the study region.

As distributions of the parameters to be estimated were almost totally unknown, a rigorous estimation of the required sample size was not possible. However, an approximate number was calculated based on the precision of estimating the proportion of agricultural shallow wells with oxygen measurements below a "safe" level (considered here to be 19.5%) [2,3]. Based on the small survey conducted by the health officers from the Bureau of Occupational and Environmental Diseases in Kamphaengphet province, 16% of wells had low-oxygen readings. Estimation of this percentage with a 95% confidence interval (CI) of ±5 percentage points would require a sample size of 207, assuming no missing or unusable data. To allow for 20% wells with unusable data, the planned sample size was raised to $207/0.8 = 259$. All wells in four villages were included in the study, and the sample size was augmented by wells from the fifth village. Ultimately, 295 agricultural shallow wells were visited for inclusion as potential study units.

Each of the 295 wells was visited between 08:00 hours and 19:00 hours during June 2007 and July 2007, which falls at the end of the dry season. Forty-two of these wells were almost full of water, with <2 m depth of air column, measured from the top of the surrounding wall, and were excluded from the study sample. Atmospheric composition of the remaining 253 shallow wells was measured using a standardized protocol.

Measurements were made using a portable confined space gas meter (EntryRAE PGM-3000 Confined Space Gas Meter 4-gas; RAE Systems, Inc., San Jose, CA, USA), which can measure the levels of $O_2$, CO, $H_2S$, and %LEL. This latter measurement represents the concentration of combustible gases as a percentage of lower explosive limit. A 12-m long "Tygon" tubing (internal diameter 0.55 cm) was attached to the inlet of the gas monitor, and the weighted end was lowered into the well atmosphere to take readings at each 1 m depth measured from the top of the surrounding wall of the well. The dead space of the Tygon tubing was calculated to be approximately 285 $cm^3$, and the airflow of the