7. Faryab: Thermogeology

7.1 What is thermogeology?

The term "thermogeology" simply refers to the science of the distribution and movement of heat within the ground, and to its exploitation by human beings for the purposes of heating and cooling. The existence and movement of heat in the ground is governed by the distribution of temperature within the ground.

The temperature of the shallow subsurface is largely governed by the annual average air temperature. At depths of a few metres, the ground heats up and cools down with the seasons, although the amplitude of the temperature swing diminishes with depth and the time lag becomes greater. Below around 6-10 m depth, the temperature of the ground, and its groundwater, becomes almost constant, at a level slightly higher than the annual average air temperature. In fact, snow cover tends to insulate the ground against the worst extremes of winter temperature, so the greater and longer the snow cover the higher the ground temperature will be, relative to annual average air temperature.

We have already seen (Chapter 2) that the annual average air temperature is around 14-15°C in Maimana, 17-18°C in Andkhoi, and 6-7°C in parts of Kohistan.

As one goes deeper into the ground, the temperature increases slowly according to the "geothermal gradient", which is typically between 1-3°C per 100 m in geologically stable areas (which Afghanistan, being part of a geologically recent orogenic belt, is not). In fact, Saba et al. (2004) cite a geothermal gradient of 2.5 to 3°C per 100 m as being typical for Afghanistan. The geothermal gradient $\Delta T/\Delta z$ is governed by Fourier's Law (Banks 2009, 2012):

$$\frac{\Delta T}{\Delta z} = \frac{q}{\lambda}$$

where $\boldsymbol{T}$ is temperature (K), $\boldsymbol{z}$ is depth (m), $\boldsymbol{q}$ is the geothermal heat flux (W/m^2) and $\boldsymbol{\lambda}$ is the bulk vertical thermal conductivity of the rock sequence (W/m/K).

7.2 Shallow subsurface temperatures

During groundwater sampling campaigns of 2013, 67 springs, 335 dug wells and 33 drilled boreholes (435 total) were visited and field pH, electrical conductivity and temperature were recorded. The sources were <100 m deep and, in most cases, <60 m deep (Figure 7.2b). These sources were in:

- Kohistan
- Bilchiragh
- Gurziwan
- Qaysar
- the area around Maimana Airport
- the four northern districts of Andkhoi, Qurgan, Qaramqol and Khani Chahar Bagh.

Figure 7.1 shows a map of the recorded groundwater temperatures. Although every effort was made to obtain representative "fresh" groundwater from the sources, it cannot be guaranteed that all samples would have been wholly adequately "purged" and thus representative of aquifer *in situ* temperatures.

Figure 7.2 shows the temperatures distributions by district as boxplots.

It will be seen that temperatures are broadly as expected, ranging from 11-13°C in Kohistan (most of the sampled points were in the lower-lying, and hence warmer, valleys of the district) to around 20°C in the northern districts around Andkhoi. In Maimana district, groundwater temperatures were typically 16-17°C, around 2°C warmer than annual average air temperatures.

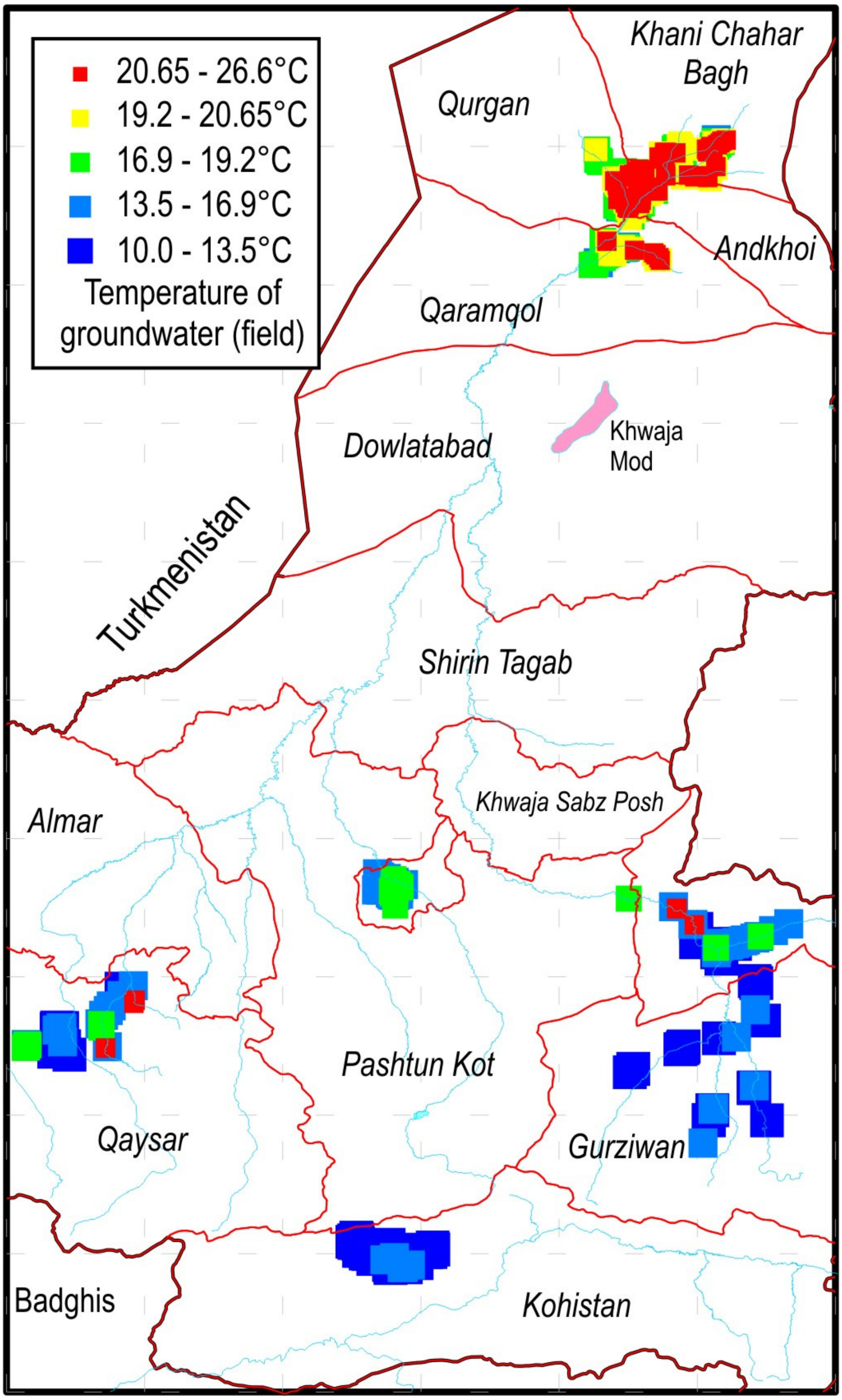
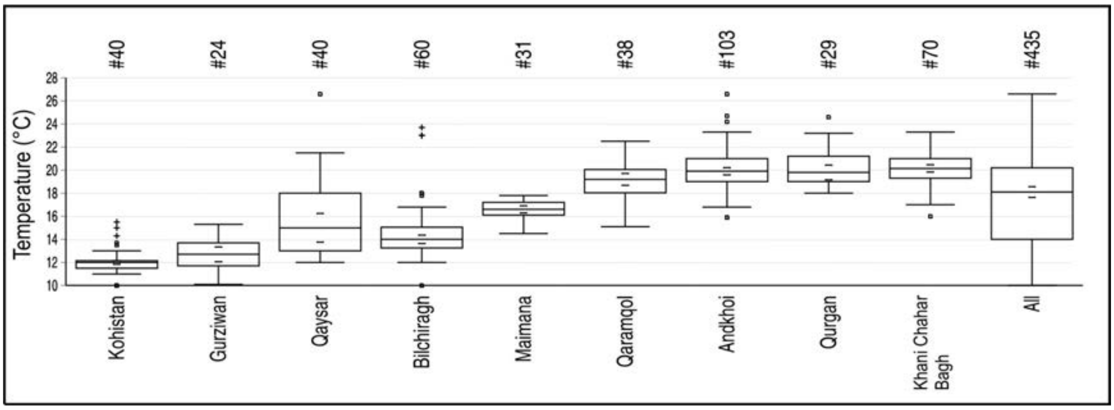


Figure 7.1. Recorded groundwater temperature (2013) in dug wells, boreholes and springs of Faryab.

7



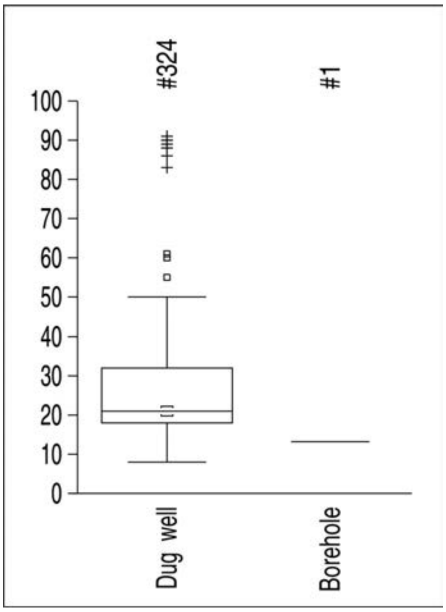


Figure 7.2a (above). Distribution of groundwater temperature (2013) by district as boxplots (435 readings total). In boxplots, the central "box" represents the interquartile range with a horizontal line as the median. The "whiskers" represent the non-outlying extraquartile range, with outliers shown as small squares (near outliers) or crosses (far outliers). Parentheses around the median represent a robust 95% confidence interval on the median. The #numbers along the top represent the number of data in each subset.

Figure 7.2b (left). Depth distribution of the 324 dug wells where temperature was recorded and the well depth was known. At only 1 drilled borehole was the depth recorded.

Temperature data have also been plotted against estimated ground elevation in Figures 7.3 and 7.4, showing how groundwater temperature increases as ground elevation drops and the climate becomes warmer towards the north. Figure 7.4 indicates a lapse rate of some 0.5°C per 100 m elevation.

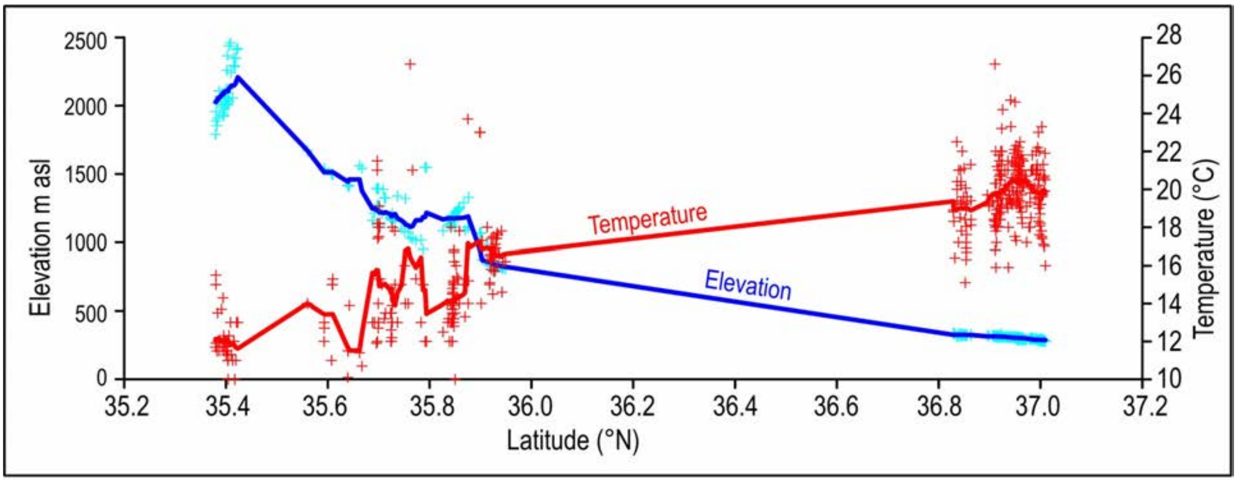


Figure 7.3. Groundwater temperature and altitude of sample location plotted against latitude in Faryab. The lines represent a moving average through the real data points (crosses).

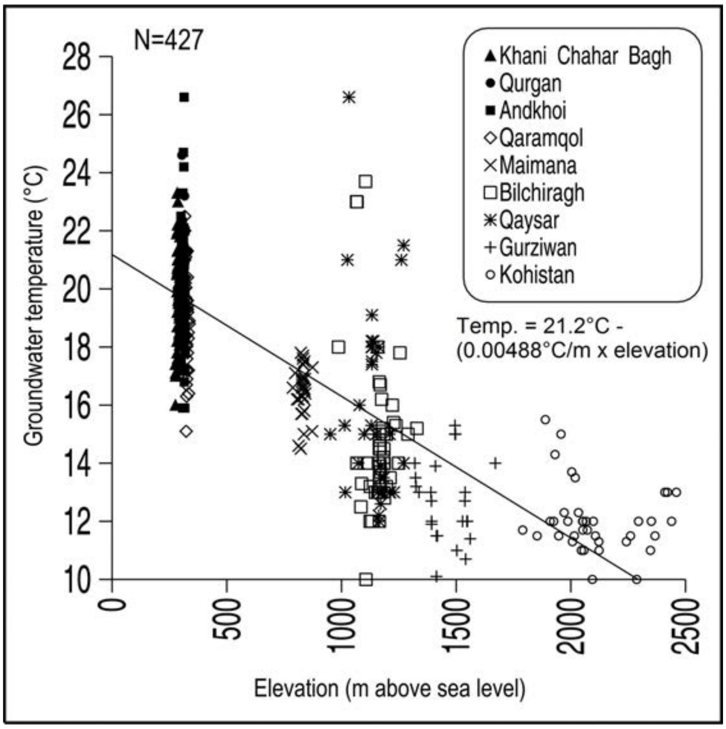


Figure 7.4. Groundwater temperature (°C) from the sampling campaign of 2013 plotted against elevation of sampling point above sea level. The line shows a best-fit linear regression, indicating an approximate lapse rate of 0.5°C per 100 m elevation.

The *lapse rate* is the rate at which atmospheric temperature decreases with increase in altitude. According to Wikipedia, the average global atmospheric lapse rate is around 0.64°C per 100m, which approximately corroborates the data from Faryab.

Where the depth of dug wells has been recorded, data have been examined to ascertain if there is any discernable increase in groundwater temperature with well depth. No such correlation has been found (Figure 7.5).

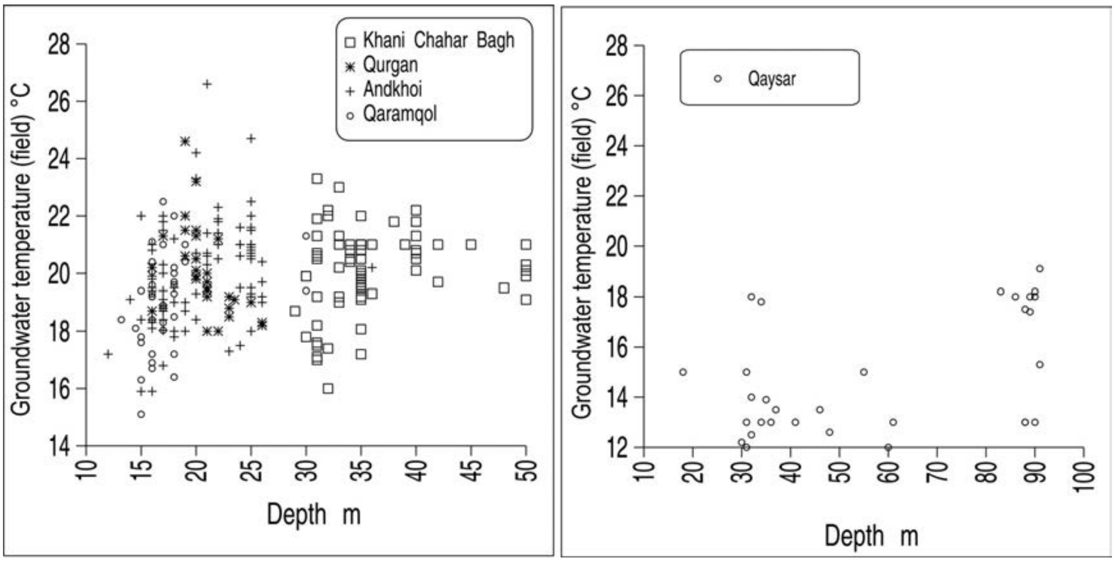


Figure 7.5. Groundwater temperature plotted against well depth for the four northern districts around Andkhoi and for Qaysar. These are almost exclusively dug wells, which do not penetrate a great distance below the water table. Hence, well depth is a good indicator of the depth of the horizon from which groundwater is derived.

7.3 Ground heating and cooling in Faryab

Areas of continental climate (extremely cold winters and hot summers) offer excellent potential for ground sourced heating and cooling. This is because, in summer, the ground is much cooler than the air, yet in winter it is much warmer.

Thus, in summer in Andkhoi, it is much more efficient to use a ground source heat pump (GSHP) to reject waste heat from buildings to the ground or to groundwater at 20°C, than to use a conventional air conditioner to reject waste heat to the outdoor air, which may have a temperature in the upper 30s°C.

In Kohistan, where the groundwater temperature may be as low as 10-11°C, one could even use the groundwater directly for space cooling, without the use of a heat pump.

In winter, when air temperatures fall close to, or below 0°C, the warm ground or groundwater, in the range 10-20°C could be very efficiently used for space heating, via a ground source heat pump.

The beauty of such systems is that the waste heat rejected to the ground in summer will tend to warm the ground up. This heat will be "stored" in the ground until winter, when it can be re-extracted again, using a ground source heat pump.

Such GSHP technology can run using brackish or even saline groundwater. By drilling heat exchangers into the ground (a so-called closed-loop system), it can even function where no groundwater is present. A modern GSHP does, however, require a reliable source of reasonably cheap electricity. In many parts of Faryab, this may be present via the import power lines running from Turkmenistan. Ground source heating and cooling technology, using the heat stored in shallow ground and groundwater, thus has considerable potential in Afghanistan.

7.4 Deeper geothermal prospects

The report by Saba et al. (2004) does not list any surface indications of geothermal prospects in Faryab Province. They suggest that the main geothermal prospects lie further south, along the Herat-Panjshir geosuture and the Chaman-Moqor fault systems of central Afghanistan. They do, however, note that high fluid temperatures can be encountered in so-called "geopressurised systems" - porous, high pressure sedimentary strata associated with the hydrocarbon reserves of the northern Afghan provinces at several km depth.

Klett et al. (2006; based on Gotgilf et al., 1969) report the following geothermal gradients from the Afghan-Tajik sedimentary basin of northern Afghanistan:

- 2.5°C per 100 m for the Neogene strata
- 3.2°C per 100 m for the Eocene-Oligocene strata
- 2.0°C per 100 m for the Palaeocene strata

Based on Krylov (1980), Klett et al. (2006) also report (again for the Afghan-Tajik basin):

- 2.4 to 3.0°C per 100 m for the upper 4.5 km of strata
- 2.5 to 2.9°C per 100 m to 6-7 km depth

Finally, Brookfield & Hashmat (2001) report a somewhat higher typical geothermal gradient of c. 3.46°C per 100 m for oil-producing wells of northern Afghanistan. Ulmishek (2004) also cites a gradient of 3.0 to 3.5°C per 100 m for the Amu Darya sedimentary basin.

A geothermal gradient of 3°C per 100 m, and a surface temperature of 20°C (annual average) would imply:

- a temperature of 50°C at 1 km depth
- a temperature of 100°C at 2.7 km depth
- a temperature of 200°C at 6 km depth.

Where porous and permeable sedimentary aquifers exist at these depths, thermal water may potentially be extracted to provide direct heating potential, or even electrical power production potential. In practice, these aquifers are most typically sandstones with intergranular porosity (as fractures tend to "close up" with great depth) but, occasionally, limestone aquifers can also retain permeability at considerable depth, depending on their karstification and weathering history.

It is anecdotally reported by hydrogeologists active in Faryab that the Ministry of Mines, Department of Oil and Gas, drilled an exploratory well into Lower Cretaceous/ Jurassic sandstones in the area to the NE of the Astana inlier in Faryab. They obtained a reported artesian flow of c. 25 L/s of overflowing saline groundwater at 45-50°C. The depth of the well is not clearly known. Such a water flux could be used for direct heating purposes. If a temperature differential of 15°C could be extracted from the water, the flux represents:

15 K x 4.2 kJ/L/K x 25 L/s = 1.6 MW of heating potential.

Unless the thermally spent water were reinjected, however, it is unlikely that such a flow rate would be sustainable in the long term.