Chapter 15C. Geohydrologic Summary of the Zarkashan Copper and Gold Area of Interest

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15C.1 Introduction

This chapter describes the geohydrology of the Zarkashan copper and gold area of interest (AOI) in Afghanistan identified by Peters and others (2007). The AOI is located in Ghazni Province in Muqur, Jaghuri, Qarabagh, Ab Band, and Gelan Districts (fig. 15C–1*a*,*b*). The AOI is located between the Arghandab River on the northwest and the Tarnak River on the southeast. The settlement of Moqur (Muqur), on the banks of the Tarnak River, is the closest large settlement and is about 6 km (kilometers) southeast of the Zarkashan mine subarea. The AOI is mountainous with a prominent northeast–southwest-trending fault-controlled fabric (Sawyer and Stoeser, 2005).

Water is needed not only to process mineral resources in Afghanistan, but also to supply existing communities and the associated community growth that may accompany a developing mining economy. Information on the climate, vegetation, topography, and demographics of the AOI is summarized to provide information on the seasonal availability of, and seasonal demands for, water. The geohydrology of the AOI is described through the use of maps of streams and irrigated areas, generalized geohydrology and topography, and well locations. Where these data are available, the depth to water and height of static water in wells are documented. The results of lineament analyses are presented to identify areas where the rock may be more fractured than in other areas, which may be an indicator of high relative water yield and storage in bedrock aquifers.

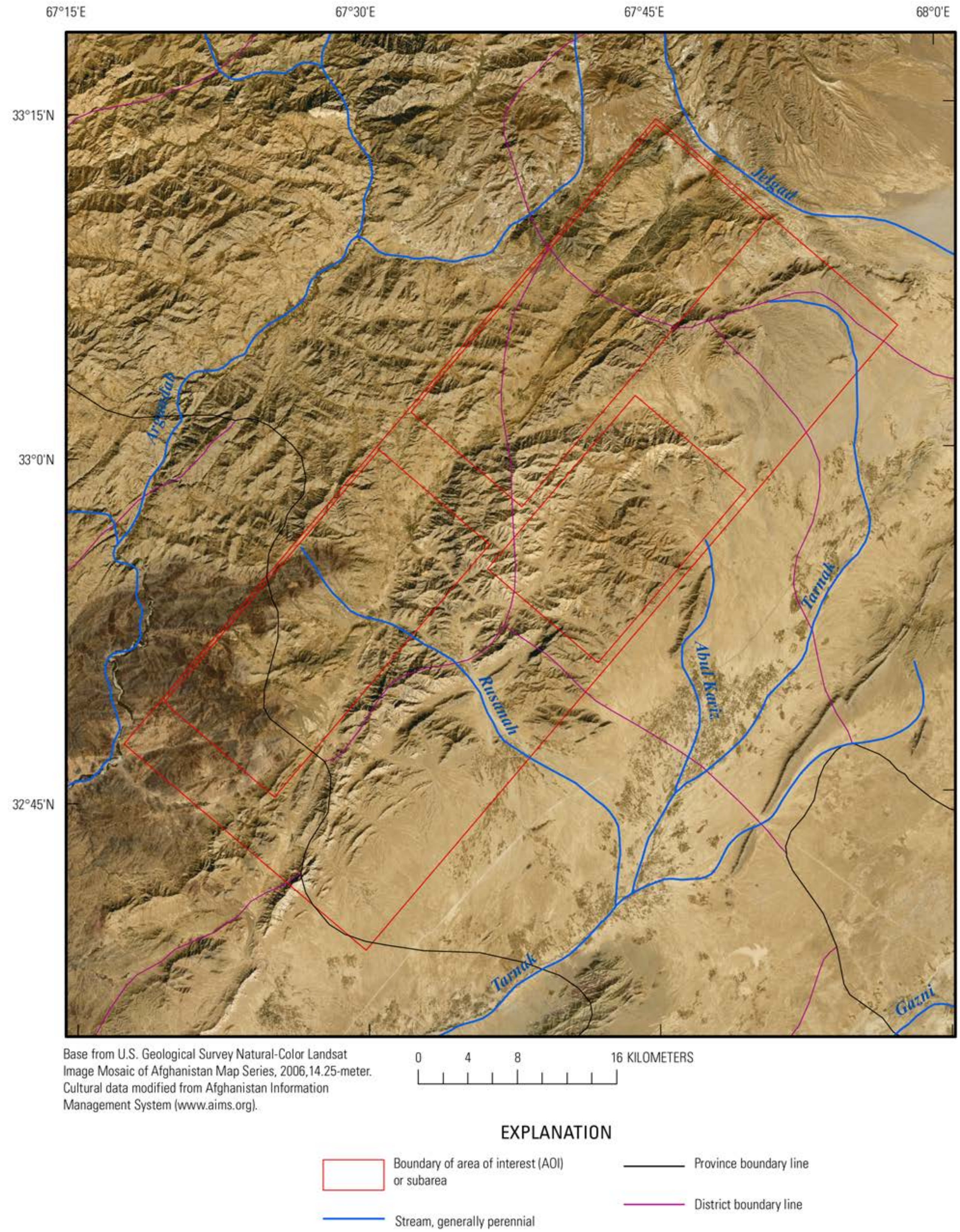
Afghanistan's recent turbulent history has left many of the traditional archival institutions in ruins, and most water-resource and meteorological data-collection activities had stopped by 1980. Recently, nongovernmental organizations (NGOs), foreign government agencies, and the Afghan government have begun water-resource investigations; however, these activities and the amount of data available are limited. This report summarizes the satellite imagery and climatic, topographic, geologic, surface-water, and groundwater data available for the AOI and surrounding areas. Geohydrologic inferences are made on the basis of an integrated analysis of these data and an understanding of conditions in other areas of Afghanistan.

15C.1.1 Climate and Vegetation

Climate information for the Zarkashan copper and gold AOI is based on data generated for the Afghanistan agricultural-meteorological (Agromet) project. Agromet was initiated by the U.S. Agency for International Development and the United Nations Food and Agriculture Organization in 2003 to establish data-collection stations and develop country-wide agrometeorological services. Scientists with the Agromet project are assisting the Afghan Government to collect and analyze agricultural and meteorological data as they relate to crop production, irrigation, water supply, energy, and aviation. The U.S. Geological Survey (USGS) assumed responsibility for the operation of the project in 2005; by the end of August 2010, 87 Agromet stations were recording precipitation data and other parameters. Additionally, the Agromet project receives data from 18 Afghanistan Meteorological Authority (AMA) weather stations. The Agromet project has developed a database that includes data collected at the Agromet stations over the past 6 years (2005-2011), data collected at the AMA weather stations, and historical data collected at weather stations from 1942 to 1993. Data collected as part of the Agromet project are compiled annually by water year (September through August) and are reported in the

Afghanistan Agrometeorological Seasonal Bulletin (Seasonal Bulletin) published by the Ministry of Agriculture, Irrigation, and Livestock. Unless otherwise specified, the Agromet data cited in this report are from the agricultural season that extends from 1 September, 2009, to 31 August, 2010.

a



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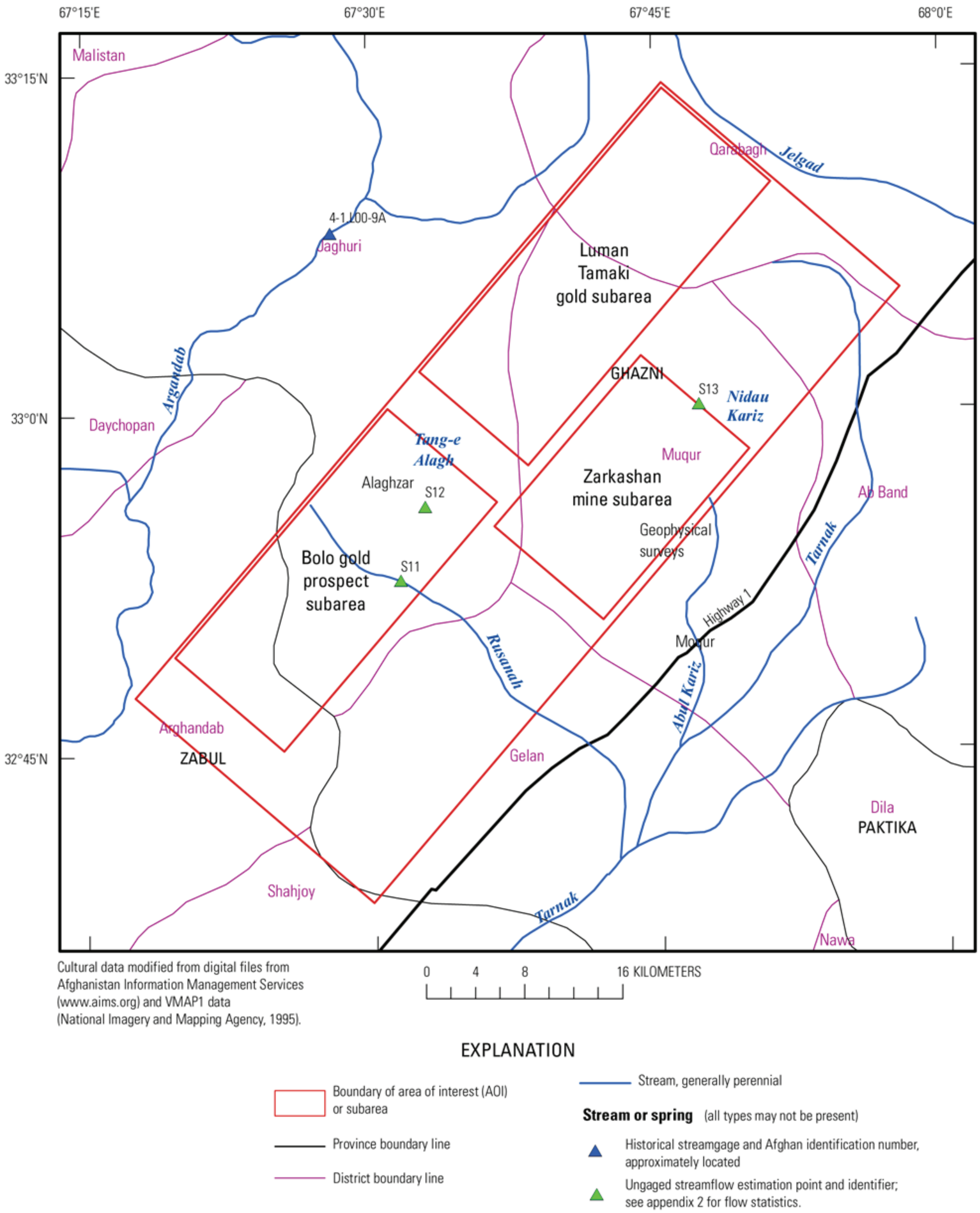


Figure 15C–1. (*a*) Landsat image showing the location of, and (*b*) place names, stream names, and streamgage station numbers in, the Zarkashan copper and gold area of interest in southeastern Afghanistan.

There are two Agromet stations in Ghazni Province for which precipitation and temperature data are available for the 2009–2010 agricultural season (Ministry of Agriculture, Irrigation, and Livestock, 2010). These stations are reported as being in the southeastern agricultural-meteorological region of Afghanistan. The closest Agromet station to the AOI is in the town of Moqur (fig. 15C–1*a*,*b*) and the other station is in Ghazni, about 90 km northeast of the AOI. Precipitation and temperature data for the Agromet station in Ghazni are presented in table 15C-1. The total rainfall recorded at the Moqur Agromet station for the 2009–2010 agricultural season was 174.5 mm (millimeters). The long-term average for this station is 391.6 mm. The Ghazni Agromet station (table 15C-1) recorded 218.3 mm of rainfall for the 2009–2010 season and has a long-term average of 308 mm (Ministry of Agriculture, Irrigation, and Livestock, 2010). The highest monthly precipitation at both stations was for February 2010—38 mm at Moqur and 60.1 mm at Ghazni. No rainfall was recorded at either station during September and October 2009. Precipitation at both stations was less than 0.6 mm during the months of April, June, and July 2010. Rainfall was recorded at both stations in the month of August 2010—33 mm at Moqur and 22.8 mm at Ghazni. The Agromet station at Ghazni also received 34 mm of precipitation in July 2010. According to the Seasonal Bulletin (Ministry of Agriculture, Irrigation, and Livestock, 2010), "The Southeast region experienced heavy rainfall during the (2009-2010) rainfall season especially during the monsoon season."

Snow was recorded at Moqur only 1 day during the 2009-2010 water year, and that was in December 2009. The settlement of Moqur is at an elevation of approximately 2,000 m (meters) above sea level (asl), and much of the AOI is more than 2,500 m asl (Bohannon, 2005a). The Afghanistan snow-depth maps for 17 January, 2010, and 30 September, 2010 (Ministry of Agriculture, Irrigation, and Livestock, 2010), show 2 to 30 cm (centimeters) of snow in the AOI in January 2010 and less than 2 cm in September 2010.

The "Potential Natural Vegetation" described in Breckle (2007) is the vegetation cover that would be present if it had not been modified by human activity. Today, as a result of continued exploitation such as grazing, farming, and deforestation, much of the original natural vegetation is found only in a few remote areas of Afghanistan. The destruction of the natural vegetation has resulted in the degradation and erosion of the soil cover in some areas. Many areas exhibit signs of long-lasting desertification caused by human activity.

The "Map of potential natural vegetation" in Breckle (2007, fig. 2) shows three vegetation zones within the AOI. The vegetation zones are controlled by elevation, climate, and amount of soil development. The lower elevations are occupied by *Pistacia atlantica* woodlands, which give way to *Amygdalus* woodlands at higher elevations. The vegetation type on the upper slopes and ridge tops is "thorny cushions, subalpine and alpine semi deserts and meadows" (Breckle, 2007). Much of the upland areas above 2,400 m asl is barren outcrop and talus slopes. Irrigated fields, orchards, and pastures are present in many of the valleys in the AOI (fig. 15C–2). Much of the native tree cover probably has been removed, especially near villages and farming areas.

15C.1.2 Demographics

The population density of the Zarkashan copper and gold AOI as mapped by LandScan (Oak Ridge National Laboratory, 2010) is shown in figure 15C–3 with a pixel resolution of about 1 km^2 (square kilometer). Several areas in the AOI have a population density greater than 500/km^2, particularly the valley that forms the Bolo Gold Prospect and Luman Tamaki Gold subareas. Some areas of this valley near streams have a population density of about 1,500/km^2. Several pixels in the Zarkashan mine subarea have a LandScan estimated population greater than 500/km^2; however, most of this subarea has a population density of 0 to less than 50/km^2. Most of the AOI, outside the subareas and away from streams, is very sparsely populated, with densities generally less than 25/km^2. The mountainous areas in the AOI are uninhabited.

Table 15C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation and temperature at the Ghazni Agrometeorological (Agromet) station 40 km northwest of the Zarkashan copper and gold area of interest, Afghanistan.

[AOI, area of interest; km, kilometers; m, meters; mm, millimeters; °C, degrees Celsius]

Agromet station	Distance from AOI center (km)	Elevation (m)	Precipitation: 2009–10 annual (mm)	Precipitation: Long-term average[1]: Annual (mm)	Precipitation: Long-term average[1]: Monthly minimum and month (mm)	Precipitation: Long-term average[1]: Monthly maximum and month (mm)	Temperature: Long-term average[1]: Minimum and month (°C)	Temperature: Long-term average[1]: Monthly mean (°C)	Temperature: Long-term average[1]: Maximum and month (°C)
Ghazni	40	3,200	218.3	308	0.2 September	63.8 April	–7.2 January	7.3	23.3 July

[1]Long-term averages are based on data from 1942 to 1993 and 2005 to 2010 as reported in the Afghanistan Agrometeorological Seasonal Bulletin (Ministry of Agriculture, Irrigation, and Livestock, 2010).

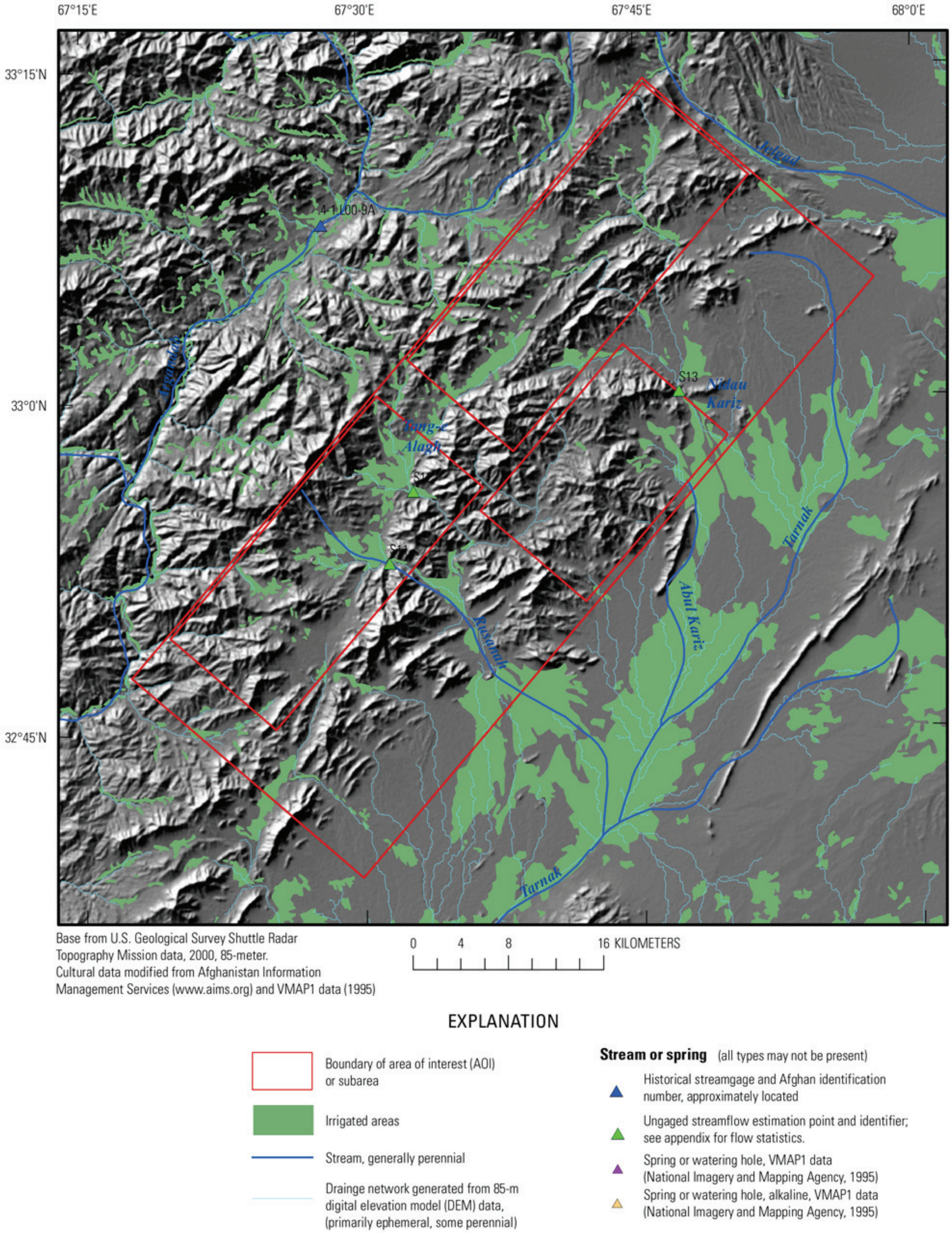


Figure 15C–2. Historical streamgage locations, digitally generated drainage network, and irrigated areas in the Zarkashan copper and gold area of interest in southeastern Afghanistan.

Moqur, the district center for Muqur District, is located about 6 km southeast of the Zarkashan mine subarea in the AOI (fig. 15C–1*a*,*b*). Extensive agricultural development is present in Moqur and adjacent to the Tarnak River. There are many small settlements and farms within the AOI that are located at or near perennial water sources. Aerial images observed using Google Earth show that villages along the southeast border of the AOI utilize karezes (traditional hand-dug water tunnels) and, most likely, shallow dug wells. The valley that roughly parallels the northwest border of the AOI contains many settlements (fig. 15C–3) and has considerable irrigated area (fig. 15C–2). According to the United Nations High Commissioner for Refugees (UNHCR) Sub-Office Central Region District Profiles (Afghanistan Information Management Service, 2002a, 2002b), there are high schools and primary schools in this valley. The settlement of Moqur is located on Highway 1 (the Afghanistan Ring Road) (fig. 15C–1), which is the primary paved road that connects Kabul with Kandahar. All the other roads within the AOI are mapped as "tracks" (Afghanistan Information Management Service, 2004).

15C.1.3 Topography and Geomorphology

The topography of the Zarkashan copper and gold AOI is dominated by the northeast-southwest -trending Tarnak River valley and a similarly trending valley that is roughly parallel to the northwest border of the AOI (fig. 15C–1*a*). A prominent ridge separates the two valleys. The ridge is about 60 km long with some peaks that are higher than 3,000 m asl (Bohannon, 2005a). The ridge slopes are dissected by ephemeral streams. The longest valleys are linear, trend northeast, and appear to be fault controlled (Davis, 2006). There are some linear, northwest-trending valleys that could also be fault controlled.

The geomorphology of the AOI is dominated by structurally controlled fluvial processes and the weathering characteristics of the bedrock outcrops. There are large deposits of undifferentiated sands and loess and fine sediments along the southeast border of the AOI that extend from the ridge fronts to the floor of the Tarnak River valley to the southeast (fig. 15C–4). These deposits are cut by active drainage channels. The Rusanah River and an unnamed ephemeral tributary drain the Bolo Gold Prospect subarea and the western slopes of the Zarkashan mine subarea (fig. 15C–1*b*). This drainage has produced a very large deposit of sands where it discharges from the mountains. Several karezes have been constructed in this alluvial fan.

The northeast-trending valley that transects the AOI is bordered by limestones and dolostones on the southeast and intrusive rocks and lavas on the northwest. Much of the valley is located at the contact between these two rock types. The range fronts on the southeast side of the valley in the sedimentary rocks are steep. The slope on the northwest side where the intrusive rocks crop out is more weathered with some alluvial cover. The maximum width of the valley in the Bolo Gold Prospect subarea is about 3 km. The width of the valley decreases to the northeast and southwest, but still has areas wide enough for farming settlements with irrigated fields (fig. 15C–2).

15C.2 Geohydrology

The geohydrology of Afghanistan has been described in general terms by Abdullah and Chmyriov (1977, book 2). As defined in their "Geology and mineral resources of Afghanistan," the Zarkashan copper and gold AOI is in the "Argandab (Arghandab) Hydrogeological Massif situated in the south-eastern part of the Helmand-Argandab Uplift and is bounded by the Mukur-Tarnak Rode (River) Fault on the south-east and a fault system on the northwest. The massif comprises Proterozoic metamorphics, Palaeozoic-Mesozoic sedimentary formations, and intrusive rocks of various ages."

The outcrops and near-surface rocks in the AOI can be grouped according to their physical and hydraulic properties. The generalized geohydrology of the AOI is shown in figure 15C–4 with the underlying topography to allow examination of the geohydrology in the context of relief. Figures 15C–5 *a* and *b* show the generalized geohydrology without topography for a clearer depiction of the geohydrologic units. Wells present in the map area (discussed in the Groundwater section) are shown in figures 15C–5*a* and *b*. Generalized geohydrologic groups were created from a country-wide geologic coverage (Doebrich and Wahl, 2006) by combining sediments and rocks into major sediment- or rock-type groups of similar hydrologic characteristics. The geohydrologic groups in or near the AOI, ranked from high to low relative hydraulic conductivity (Freeze and Cherry, 1979, table 2.3), are "river channel; sands, undifferentiated; conglomerate sediments and rocks; loess and fine sediments; limestones and dolostones; sedimentary rocks; metamorphic rocks; and intrusive rocks and lavas" (figs. 15C–4 and 15C–5*a*). Doebrich and Wahl (2006) used geologic maps at a scale of 1:250,000, modified from Russian and Afghan Geological Survey (AGS) mapping, to generate the country-wide geologic coverage. The 1:250,000-scale geologic map that covers this AOI is provided by Sawyer and Stoeser (2005).

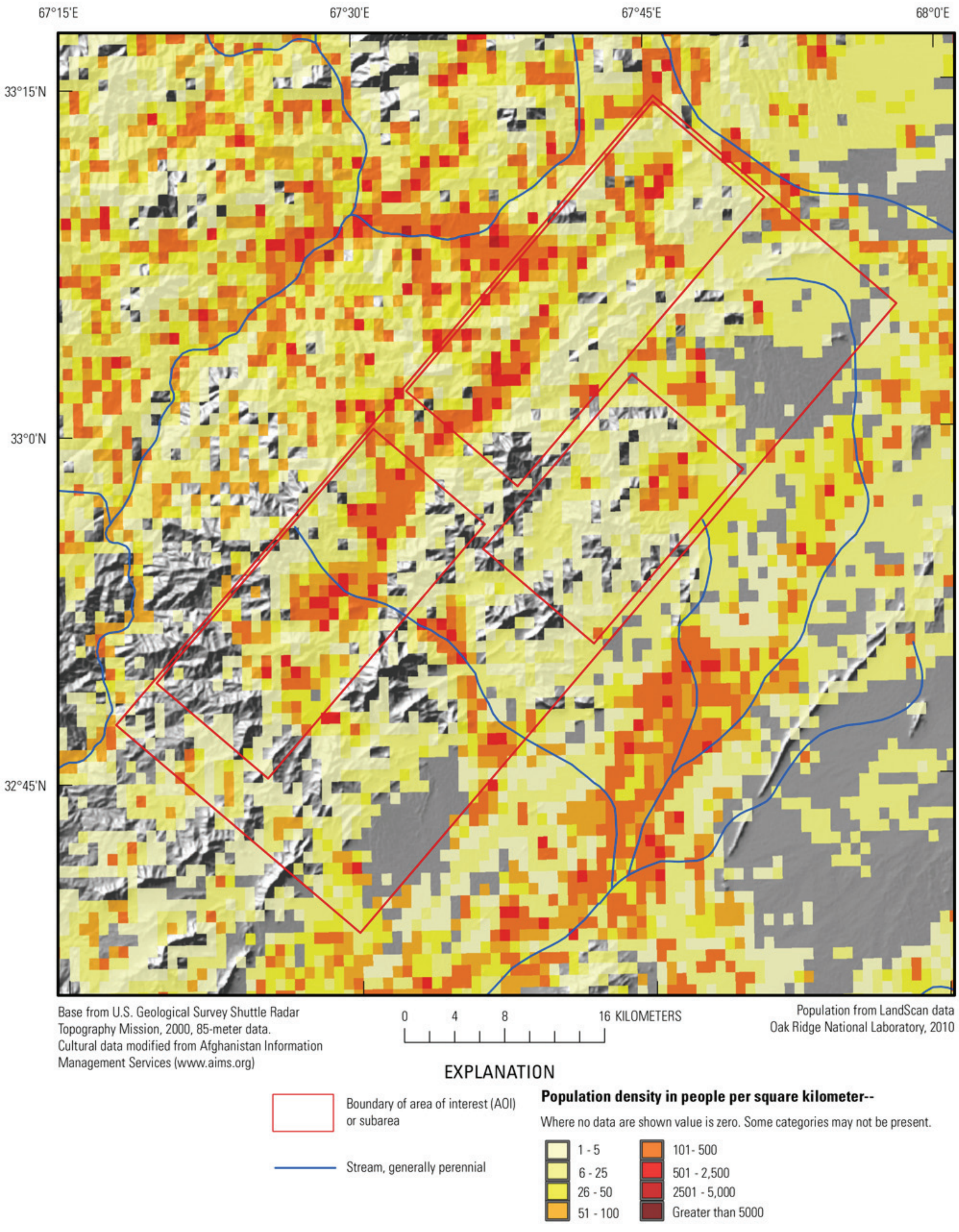


Figure 15C–3. Population density of the Zarkashan copper and gold area of interest in southeastern Afghanistan.

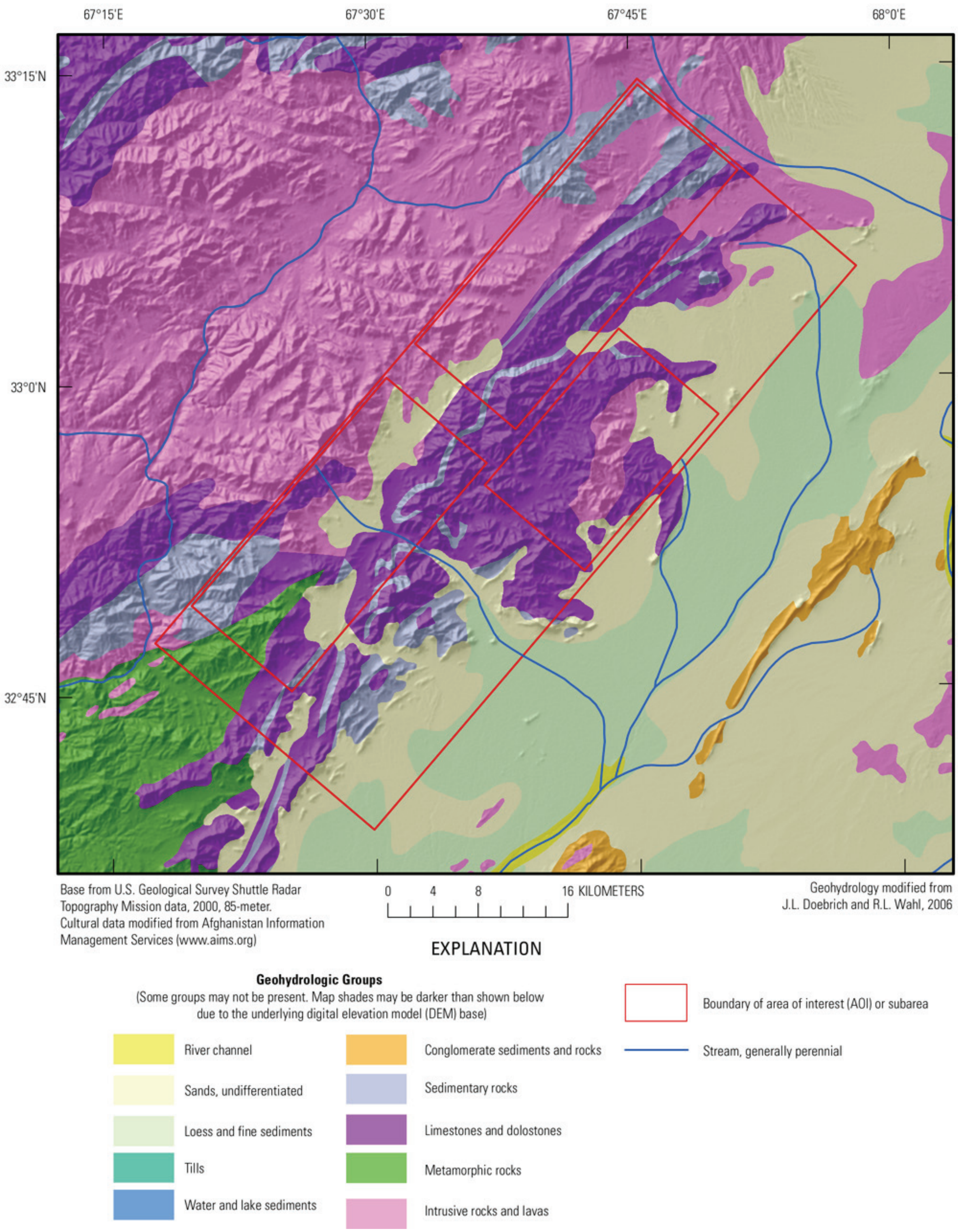
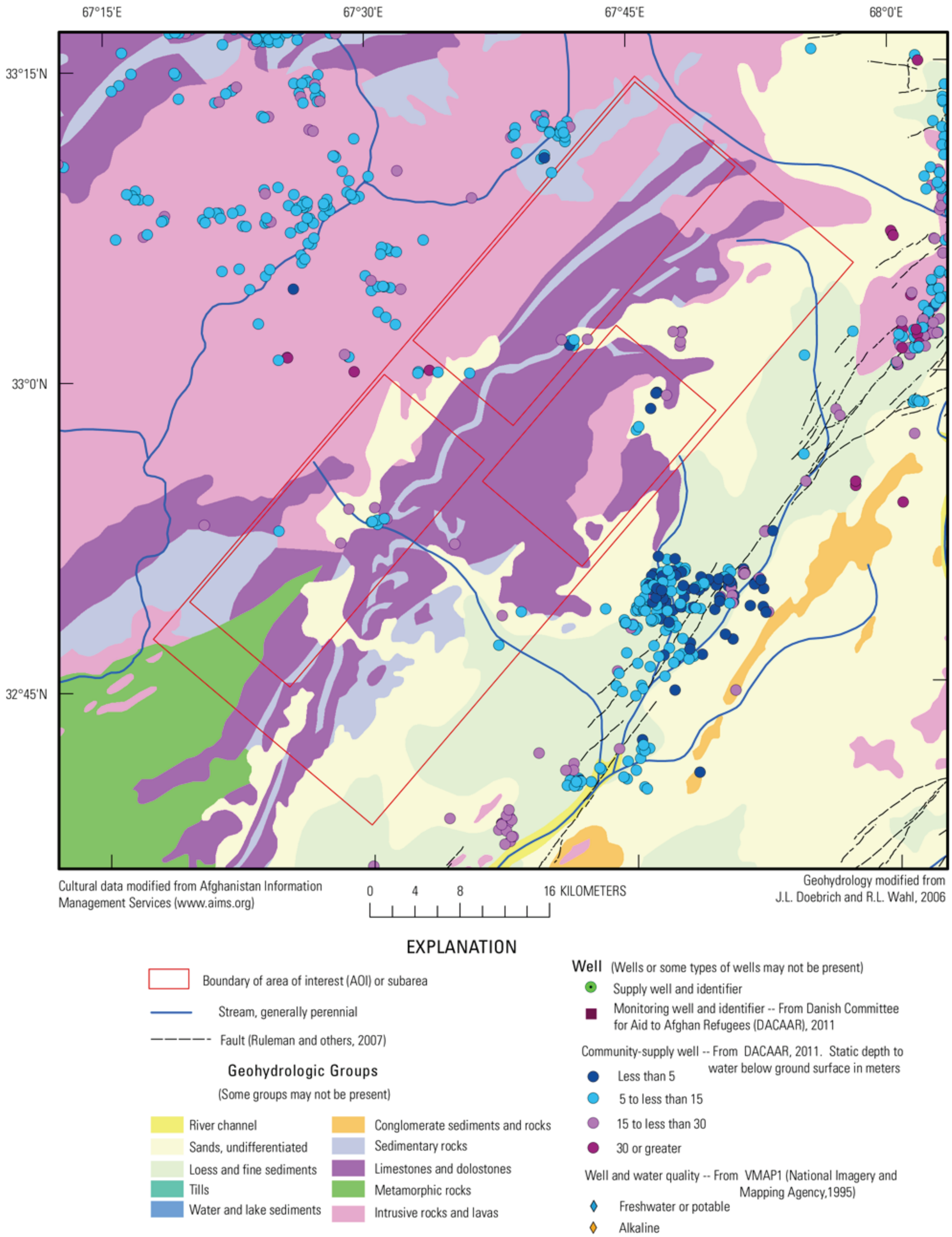


Figure 15C–4. Topography and generalized geohydrology in the Zarkashan copper and gold area of interest in southeastern Afghanistan.

a


67°15'E
67°30'E
67°45'E
68°0'E
33°15'N
33°0'N
32°45'N
Cultural data modified from Afghanistan Information Management Services (www.aims.org)
0 4 8 16 KILOMETERS
Geohydrology modified from J.L. Doebrich and R.L. Wahl, 2006
EXPLANATION
Boundary of area of interest (AOI) or subarea
Stream, generally perennial
Fault (Ruleman and others, 2007)
Geohydrologic Groups
(Some groups may not be present)
River channel
Sands, undifferentiated
Loess and fine sediments
Tills
Water and lake sediments
Conglomerate sediments and rocks
Sedimentary rocks
Limestones and dolostones
Metamorphic rocks
Intrusive rocks and lavas
Well (Wells or some types of wells may not be present)
Supply well and identifier
Monitoring well and identifier -- From Danish Committee for Aid to Afghan Refugees (DACAAR), 2011
Community-supply well -- From DACAAR, 2011. Static depth to water below ground surface in meters
Less than 5
5 to less than 15
15 to less than 30
30 or greater
Well and water quality -- From VMAP1 (National Imagery and Mapping Agency,1995)
Freshwater or potable
Alkaline

b

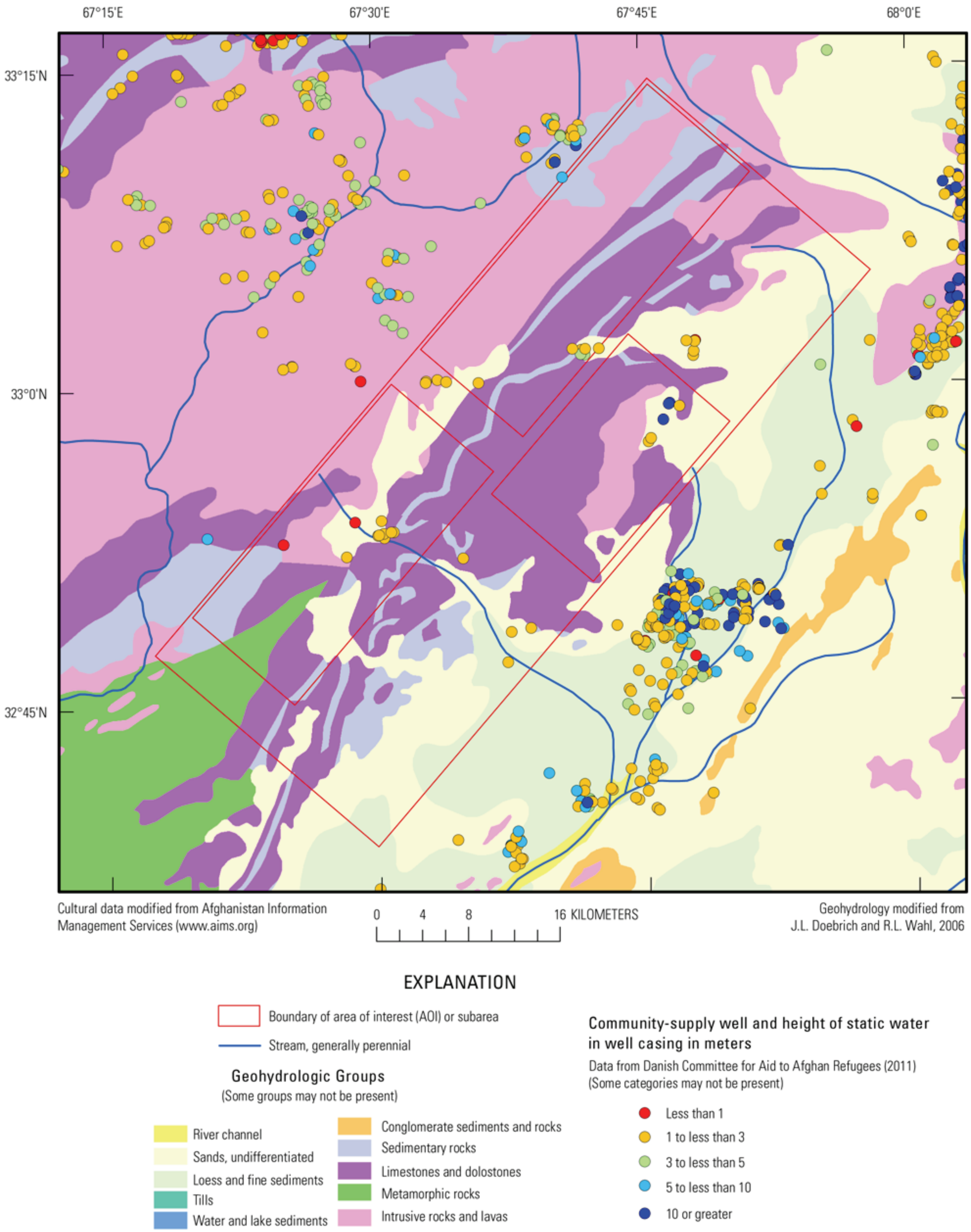


Figure 15C–5. *(a)* Generalized geohydrology, mapped faults, well locations, and depth to water, and *(b)* geohydrology and height of static water in well casings in community supply wells in the Zarkashan copper and gold area of interest in southeastern Afghanistan.

The unconsolidated units constitute the alluvial deposits along the southeast border of the AOI and in the valley that transects the middle of the AOI (figs. 15C–4 and 15C–5*a*,*b*). The consolidated rocks include sedimentary rocks; limestones and dolostones; metamorphic rocks; and intrusive rocks and lavas. This grouping also reflects the type and amount of porosity in these geohydrologic groups. The sedimentary rocks group (detrital sedimentary rocks such as sandstone and conglomerate) and the limestones and dolostones group both have interstitial porosity. Both these groups can also have secondary fracture porosity, which can be very large in limestone solution cavities (caverns). The sedimentary rocks group and the limestones and dolostones group are potential aquifers in the AOI. These rocks crop out in a northeast-trending linear pattern through the middle of the AOI (fig. 15C–4).

Rocks in the intrusive rocks and lavas group generally have minimal matrix (interstitial) porosity. The porosity in this group is a result of secondary fracturing resulting from either cooling or tectonic activity. In the absence of fractures, the porosity of intrusive rocks such as granites is low. The presence of faults and associated fracture zones can increase the hydraulic conductivity of intrusive rocks and lavas. The metamorphic rocks have low matrix porosity but, depending on the degree of metamorphism, interstitial voids may still exist in the rock. The movement of fluids through connected pore spaces in metamorphic rocks could be preferentially oriented parallel to bedding. The fracture porosity in metamorphic rocks can result from compaction foliation and be preferentially oriented along bedding. Secondary fracture porosity in metamorphic rocks can also be the result of tectonic activity. Near faults and associated fracture zones, the porosity could be significant. The intrusive rocks are present on the northwest edge of the AOI and there is an isolated outcrop intruded into the limestone in the Zarkashan mine subarea (fig. 15C–4). The metamorphic rocks are confined to the western corner of the AOI.

Structurally, the AOI is within the Chaman Fault System (Ruleman and others, 2007), specifically the Mokur (Moqur) fault splay. The primary sense of displacement on the Chaman Fault System is left-lateral strike slip. The Mokur fault shows evidence of Quaternary activity and has northeast-trending, continuous, linear fault scarps on piedmont and intra-basin alluvium of the Tarnak River valley (fig. 15C–5*a*). Northwest of the main fault trace, older, discontinuous scarps are present along the range front, suggesting southeast-verging thrust-fault activity along this fault system (Ruleman and others, 2007). The proximity of the Mokur fault, especially with Quaternary activity, could increase the number of tectonically induced fractures in the AOI.

15C.2.1 Surface Water

A network of major, mostly perennial streams, modified from AIMS (Afghanistan Information Management Services, 1997) and VMAP1 (National Imagery and Mapping Agency, 1995), is shown in figure 15C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), is shown in figure 15C–2. The Zarkashan copper and gold AOI is between the Tarnak and Arghandab Rivers and, although there are no perennial streams in the AOI, there are some large ephemeral streams (figs. 15C–1*b* and 15C–2). Historical streamgage data are available for two streamgage stations in the vicinity of the AOI (Williams-Sether, 2008). The streamgage station on the Arghandab River at Sang-i-Masha (Afghan identification number 4-1.L00.9A) is about 12 km northwest of the northeast corner of the Bolo Gold Prospect subarea (table 15C-2, fig. 15C–2). This station is at an elevation of 2,303 m asl, has a drainage area of 2,155 km^2, and has a period of record that extends from 22 June, 1969, to 30 September, 1980 (Williams-Sether, 2008). The annual mean streamflow for the period of record was 8.89 m^3/s (cubic meters per second), with a standard deviation of 3.33 m^3/s. The annual mean streamflow per unit area for this station is 0.0041 m^3/s/km^2 (cubic meters per second per square kilometer). The month with the highest annual mean streamflow was April, with 29.3 m^3/s, and the month with the lowest annual mean streamflow was September, with 3.98 m^3/s. The Arghandab River above the streamgage station at Sang-i-Masha drains a very mountainous region, with peaks higher than 3,500 m asl and a few peaks higher than 4,000 m asl (Bohannon, 2005*a,b*). Precipitation in this area is probably similar to that in other mountainous regions in Afghanistan, with most precipitation falling as snow during the winter season (Breckle, 2007). The seasonal melting and runoff account for the increase in streamflow during the months of March, April, and May (Williams-Sether, 2008). Statistical summaries of streamflow data for all available historical gages in Afghanistan can be accessed at *http://afghanistan.cr.usgs.gov/water.php.*

The station on the Tarnak River near Shahjuy (Afghan identification number 4-1.21R-7A) is about 40 km southwest of the district center of Moqur (table 15C-3). This station is at an elevation of 1,043 m asl, has a drainage area of 8,120 km^2, and was in service from 19 February, 1969, to 30 September, 1980. The annual mean streamflow for the period of record was 1.35 m^3/s, with a standard deviation of 0.38 m^3/s. The annual mean streamflow per unit area for this station is 0.0002 $m^3/s/km^2$. The month with the highest annual mean streamflow during the period of record was March, with 2.36 m^3/s, and the month with the lowest annual mean streamflow was September, with 0.75 m^3/s. The highest maximum monthly mean streamflow was 5.90 m^3/s, in March 1980. The lowest minimum monthly mean streamflow was 0.407 m^3/s, in December 1974. The headwaters of the Tarnak River consist of a number of small streams that begin as streamflow from the alluvial valley-fill sediments north of Moqur. Several small tributary streams join the Tarnak River along its course, and runoff from irrigated fields probably contributes some flow as well. Seasonal runoff from the higher elevations in the AOI would increase the flow in the Tarnak River, as evidenced by the occurrence of the highest flows in March (table 15C–3), and provide recharge to the shallow alluvial aquifer.

An ephemeral stream with several tributaries flows through the northeast-trending valley that transects the AOI (fig. 15C–2). These ephemeral streams probably flow during the spring snow melt. The amount of vegetation and number of buildings visible in aerial images along these ephemeral streams indicate that runoff and recharge events are of sufficient volume and duration to provide adequate water resources for irrigation and domestic supply. The presence of incised drainage channels on the largest alluvial fans on the southeast side of the AOI are evidence that flow occasionally occurs. No springs are identified in the AOI by VMAP1 (National Imagery and Mapping Agency, 1995) (fig. 15C–2), but some springs probably are present in some areas of the AOI, such as downgradient from lineaments.

Streamflow statistics were estimated for selected ungaged streams that may be prominent in the AOI or subareas to provide some probable estimates of flow for these locations. Streamflow statistics, presented in appendix 2, were calculated for points S11, S12, and S13 (figs. 15C–1*b* and 15C–2) using a drainage-area-ratio method (Olson and Mack, 2011) based on historical flows at the Syahgel River at Syahgel (Afghan identification number 3-5R00-3T). The Syahgel River at Syahgel streamgage station is located about 90 km northeast of the center of the AOI and was selected as the most representative historical gage, based on drainage-basin size and location, for use with this method at this location. Point S11 is on the Rusanah River in the AOI. The other two points are also on ephemeral streams. The estimated mean annual streamflow for point S11 (app. 2), with a drainage area of 105 km^2, is about 0.13 m^3/s. By applying the same method, the estimated mean annual streamflow for points S12 and S13 is 0.21 and 0.41 m^3/s, respectively. The seasonal timing of maximum and minimum monthly streamflows, with high flows in the mid to late spring and low flows in late fall and winter, probably is similar to that at the Syahgel River at Syahgel station (app. 2).

15C.2.2 Groundwater

The groundwater resources in the Zarkashan copper and gold AOI are not well defined at this time. The agricultural development in the stream valleys and on the alluvial fans indicates that the shallow groundwater resources are sufficient for irrigation and domestic consumption. Vegetation lineaments and some very small farming areas are located in ephemeral stream valleys mapped as bedrock outcrops. There is minimal alluvial cover in these areas; therefore, it is likely that the shallow alluvial aquifer has some limited storage capacity. Recharge to these areas probably consists of infiltration with a minor component of discharge from the bedrock.

Table 15C–2. Statistical summary of monthly and annual mean streamflows for the Arghandab River above Sang-i-Masha streamgage station.

[m^3/s, cubic meters per second]

Month	Maximum		Minimum		Mean			
	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Standard deviation (m^3/s)	Coefficient of variation	Percentage of annual streamflow
October	8.92	1980	2.59	1972	4.90	1.80	0.37	4.60
November	10.4	1980	3.77	1972	6.12	2.19	0.36	5.74
December	10.3	1980	4.25	1971	6.10	1.84	0.30	5.72
January	9.54	1980	3.78	1971	5.87	1.80	0.31	5.51
February	10.2	1980	3.84	1971	6.15	1.89	0.31	5.77
March	20.2	1973	5.54	1971	12.0	4.41	0.37	11.2
April	59.4	1980	5.97	1971	29.3	15.4	0.53	27.5
May	58.9	1976	2.11	1971	15.3	9.30	0.61	14.3
June	10.1	1980	0.775	1971	5.57	3.09	0.56	5.23
July	17.0	1976	0.632	1971	6.33	5.34	0.84	5.95
August	11.6	1976	1.80	1971	4.95	2.99	0.60	4.65
September	7.50	1976	1.15	1971	3.98	1.93	0.48	3.73
Annual	**15.1**	**1980**	**3.16**	**1971**	**8.89**	**3.33**	**0.37**	**100**

Table 15C–3. Statistical summary of monthly and annual mean streamflows for the Tarnak River near Shahjuy streamgage station.

[m^3/s, cubic meters per second]

Month	Maximum		Minimum		Mean			
	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Standard deviation (m^3/s)	Coefficient of variation	Percentage of annual streamflow
October	1.24	1980	0.500	1974	0.79	0.20	0.25	4.94
November	2.20	1970	0.484	1974	1.16	0.42	0.36	7.24
December	2.14	1970	0.407	1974	1.36	0.50	0.37	8.48
January	2.81	1972	0.413	1974	1.50	0.67	0.44	9.39
February	3.61	1979	0.486	1974	1.90	0.94	0.50	11.9
March	5.90	1980	1.08	1969	2.36	1.32	0.56	14.7
April	3.76	1972	0.883	1978	1.90	0.98	0.52	11.8
May	2.69	1976	0.660	1978	1.22	0.67	0.55	7.58
June	1.75	1976	0.527	1975	0.82	0.38	0.46	5.13
July	3.75	1978	0.522	1971	1.07	0.92	0.86	6.71
August	2.60	1978	0.573	1972	1.19	0.73	0.61	7.45
September	1.26	1976	0.471	1977	0.75	0.26	0.34	4.68
Annual	**1.88**	**1976**	**0.676**	**1974**	**1.35**	**0.38**	**0.28**	**100**

Thirty-eight shallow community groundwater-supply wells have been installed in the AOI by NGOs. Information about these wells can be found in a database maintained by the Danish Committee for Aid to Afghan Refugees (DACAAR) (2011). Many additional wells are present in the Moqur area in the Tarnak River valley southeast of the AOI (fig. 15C–5*a*). Well-depth and static-water-level information is available for most of the wells in this database. Available well-construction information is limited; however, most wells are "tube" wells (driven wells with polyvinyl chloride (PVC) casing) or dug wells with concrete-ring casing. Wells are generally installed in unconsolidated sediments, completed a few meters below the depth at which water was first encountered, and equipped with a hand pump. The depth to water in most wells was less than 15 m; the median was 11 m. The wells in the AOI are shallow, with a median depth of 15 m. One well is 37 m deep; all others are less than 24 m deep. The water level in the deepest (37-m-deep) well also was deep (35 m). Figure 15C–5*b* shows the height of static water in the casings of the water-supply wells (well depth minus static depth to water). The median height of static water in well casings in the AOI was 1.5 m. Wells such as these, with little static water, were found to be vulnerable to seasonal water-level fluctuations and becoming dry for extended periods of time, or even permanently, in areas of the Kabul Basin where groundwater withdrawals are increasing (Mack and others, 2010).

Many of the wells in the AOI are located in the sands, undifferentiated group. The wells that are located in areas mapped as bedrock are probably actually in unconsolidated sediments that overlie the bedrock, such as where there are concentrations of wells along the streams in areas mapped as bedrock outcrops (fig 15C–5*a*). The typical drilling method used in the area (driven or dug wells) cannot penetrate large thicknesses of consolidated rock. The bedrock outcrops in the AOI that have no or very thin alluvial cover generally are very sparsely or not inhabited (fig. 15C–3). The alluvial-sediment-filled valley in the center of the AOI has an area of about 40 km^2. The depth to water in the community supply wells in the valley generally ranges from 5 to less than 15 m (fig. 15C–5*a*).

There are no groundwater monitoring wells (GWMs) in the AOI (fig. 15C–5*a*); however, GWM 7, monitored by DACAAR (Danish Committee for Aid to Afghan Refugees, 2011) for groundwater levels and specific conductance, is about 45 km northeast of Moqur in the Tarnak River flood plain in a similar geohydrologic setting. Hydrographs of water levels, provided by DACAAR, are shown in appendix 3. The hydrographs show the date in week number and year, groundwater specific conductance in microsiemens per centimeter at 25°C (µS/cm), and depth to water in meters below ground surface (bgs). The well is 56 m deep with an average water level of 4.8 m bgs. The water-level hydrograph shows distinct peaks that represent annual water-level highs and lows. The highs generally occur during the spring and summer, which probably are times of flow and recharge in the ephemeral stream. The maximum water level was 3.8 m bgs in June 2006. The water-level lows occur during the winter months. The minimum water level was about 6.6 m bgs in December 2007 and January 2009. A general water-level decline in the well during the period of record can be seen. This decline could represent the effects of groundwater withdrawals or variations in precipitation and (or) potential recharge. The average specific conductance is 544 µS/cm. No lithostratigraphic information is reported for this well, but the well is located on an alluvial fan approximately 350 m from the center of an ephemeral stream channel. The geology of this area (Sawyer and Stoeser, 2005) consists of loess and fine sediments that probably are underlain by gravel and sand. Aerial images of this area viewed using Google Earth show a number of karezes with irrigation canals located in the ephemeral stream near this well.

Geophysical surveys (direct-current (DC) resistivity) conducted by German and Afghan teams in the early 1960s (Homilius, 1968, 1969) were used to investigate valley-fill deposits in the western side of the Zarkashan mine subarea (fig. 15C–1*b*). DC resistivity lines indicated sediment thicknesses of about 30 m at the head of the valley in an area about 1 km wide. Test drilling toward the center of the valley on the western side of the Zarkashan mine subarea, where the valley is several kilometers wide, indicates sediment thicknesses of 400 m. This valley is small compared to the Bolo Gold Prospect subarea valley, and it is likely that sediment thicknesses are more than 400 m in the Bolo subarea. The DC resistivity soundings identified areas of coarse-grained, saturated sediments in the Zarkashan mine subarea. It is possible that similar sediments in the AOI would serve as aquifers with favorable transmissivity and storage.

There are two U.S. government-drilled water-supply wells in the province center of Ghazni, about 60 km northeast of the AOI, which were the closest deep wells to the AOI known to this investigation. The wells were completed in unconsolidated basin-fill sediments. The wells were at depths of 111 and 124 m bgs with static water levels of about 45.5 m bgs. The static water level in the wells is about 45 m above the top of the well screen. The wells are located in the Ghazni River valley, where hydrogeologic conditions are similar to those in the Tarnak River valley (Sawyer and Stoeser, 2005). It is possible that an aquifer with similar characteristics extends to the southwest beneath the Tarnak River valley adjacent to the AOI. If so, this aquifer could represent a substantial groundwater source that might support additional withdrawals with minimal impact on local water resources. Because precipitation rates in the area are low, however, it is likely that deep groundwater is old water that is recharged very slowly. Wells would need to be sited to avoid interference with existing water-supply wells and other natural or manmade water sources, such as springs and karezes. Well drilling and hydraulic testing would help to adequately characterize the hydrologic properties of this deep aquifer.

15C.2.3 Lineament Analyses

Lineaments are photolinear features that could be the result of underlying zones of high-angle bedrock fractures, fracture zones, faults, or bedding-plane weaknesses. Lineament analyses of the Zarkashan copper and gold AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011) were conducted using DEM and natural-color satellite imagery (fig. 15C–6) and Advanced Spaceborne Thermal Emission and Reflection Radiometry (ASTER) satellite imagery (fig. 15C–7*a*,*b*). Lineament identification and analysis have long been used as a reconnaissance tool for identifying areas in carbonate bedrock environments where groundwater resources are likely to be found (Lattman and Parizek, 1964; Siddiqui and Parizek, 1971). Lineament analysis is increasingly used to identify areas of high relative well yields in other bedrock settings, including crystalline bedrock (Mabee, 1999; Moore and others, 2002). The lineaments shown in figure 15C–6 were delineated visually, whereas those in figure 15C–7 were delineated using an automated process and on the basis of the multispectral characteristics of the land surface (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011). Water wells in bedrock aquifers generally are most productive where boreholes are located in areas of highly fractured bedrock. Areas where lineament density is high (figs. 15C–6 and 15C–7*a*,*b*) potentially are areas where bedrock fractures are more prevalent than in other areas of the AOI. Lineaments provide an indication of areas that warrant further investigation for optimal bedrock water-well placement. Lineaments may also indicate areas of preferential flow and storage of groundwater, and areas with a high density of lineaments may indicate high secondary porosity. Any lineament analyses, including those presented in this investigation, need to be corroborated by field investigations and additional data to confirm the nature of the lineaments and their relation to water-filled bedrock fracture zones.

The northeasterly trend of the lineaments in the AOI (figs. 15C-6 and 15C-7*a,b*) reflects the geologic structure of the AOI (fig. 15C–4), and many lineaments are probably caused by bedding-plane weaknesses. Bedrock water wells installed near or in line with such features may have greater yields than wells in other areas. Where lineaments intersect, there may be an increased potential for enhanced transmissivity. Different lineament densities were found with the different platforms used (figs. 15C–6 and 15C–7*a*,*b*); however, the lineament density in the Luman Tamaki Gold subarea generally was greater than that in other areas of the AOI.

15C.3 Summary and Conclusions

The Arghandab River is located just outside the Zarkashan copper and gold area of interest (AOI) to the northwest, and is the largest perennial stream near the AOI. There are no perennial and few ephemeral streams in the AOI. Estimated mean annual streamflow for three points on ephemeral streams in the AOI ranged from 0.13 to 0.41 m^3/s (cubic meters per second). The flow in the ephemeral streams is probably an important source of recharge to the shallow alluvial aquifers in the stream valleys. As with all surface water in Afghanistan, close monitoring of any additional diversion and use would help to prevent overuse and degradation of this resource.

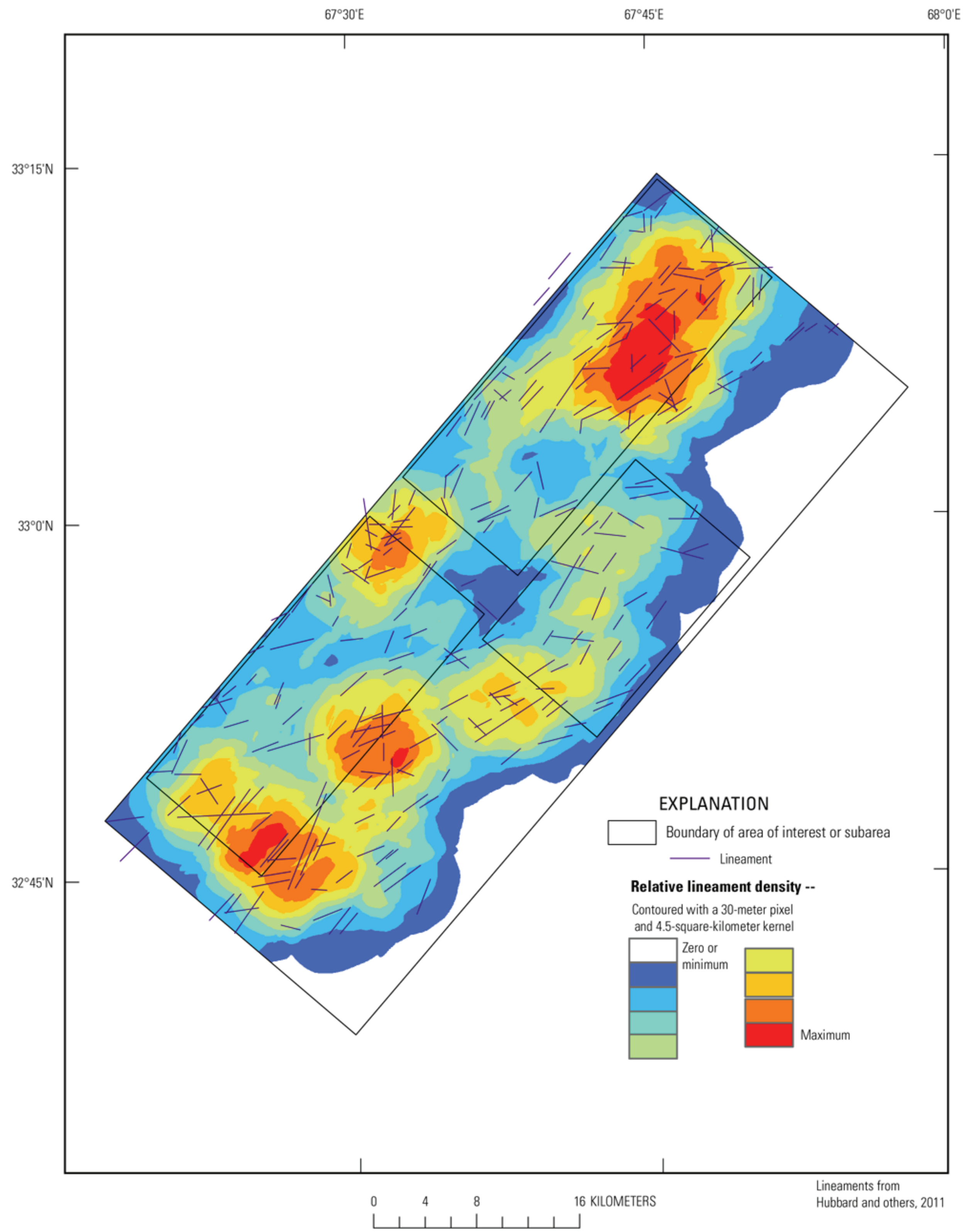
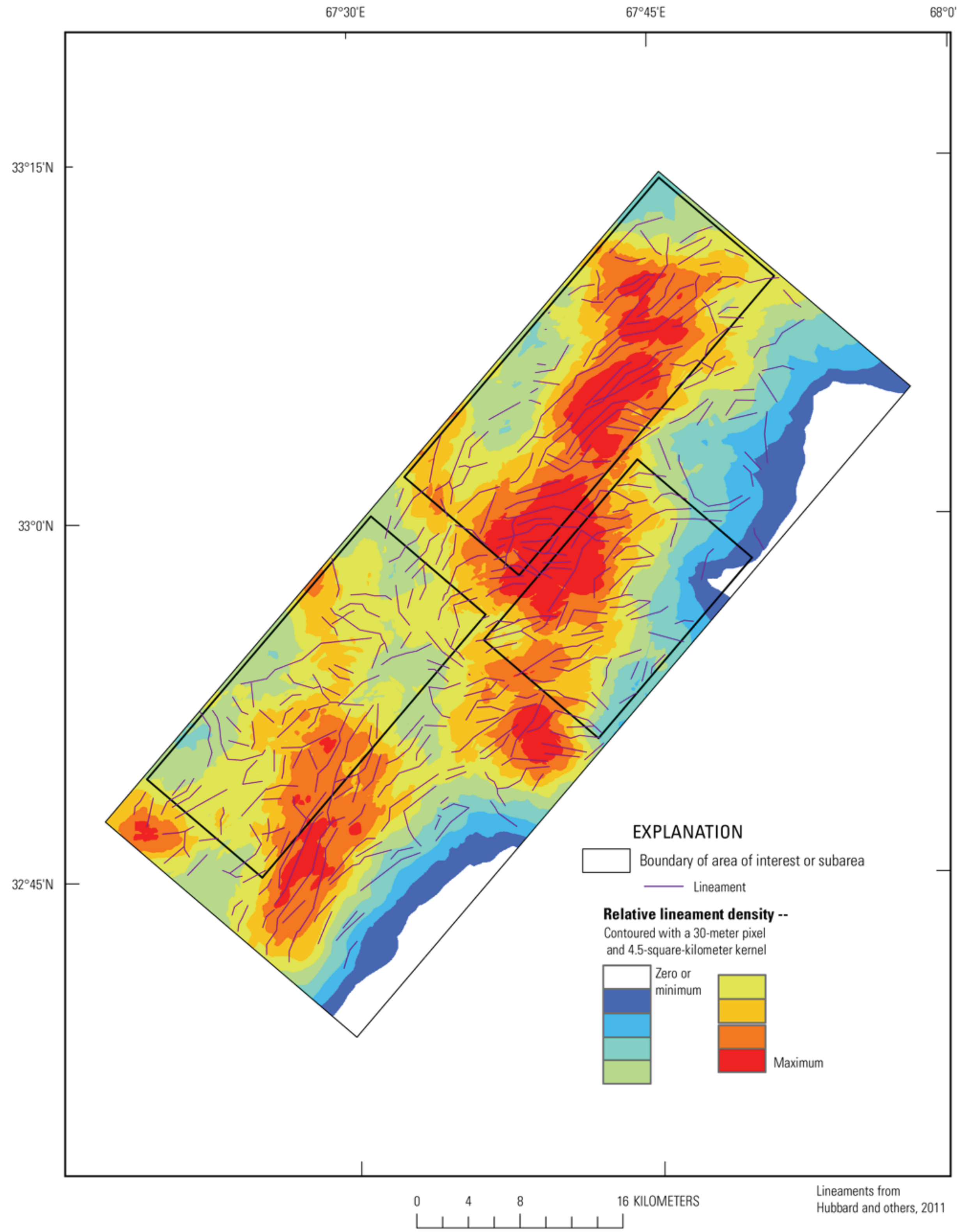


Figure 15C–6. Lineaments and lineament density based on 30-meter digital-elevation-model data and natural-color Landsat imagery in the Zarkashan copper and gold area of interest in southeastern Afghanistan.

a


67°30'E
67°45'E
68°0'E
33°15'N
33°0'N
32°45'N
EXPLANATION
Boundary of area of interest or subarea
Lineament
Relative lineament density --
Contoured with a 30-meter pixel and 4.5-square-kilometer kernel
Zero or minimum
Maximum
0 4 8 16 KILOMETERS
Lineaments from Hubbard and others, 2011

b

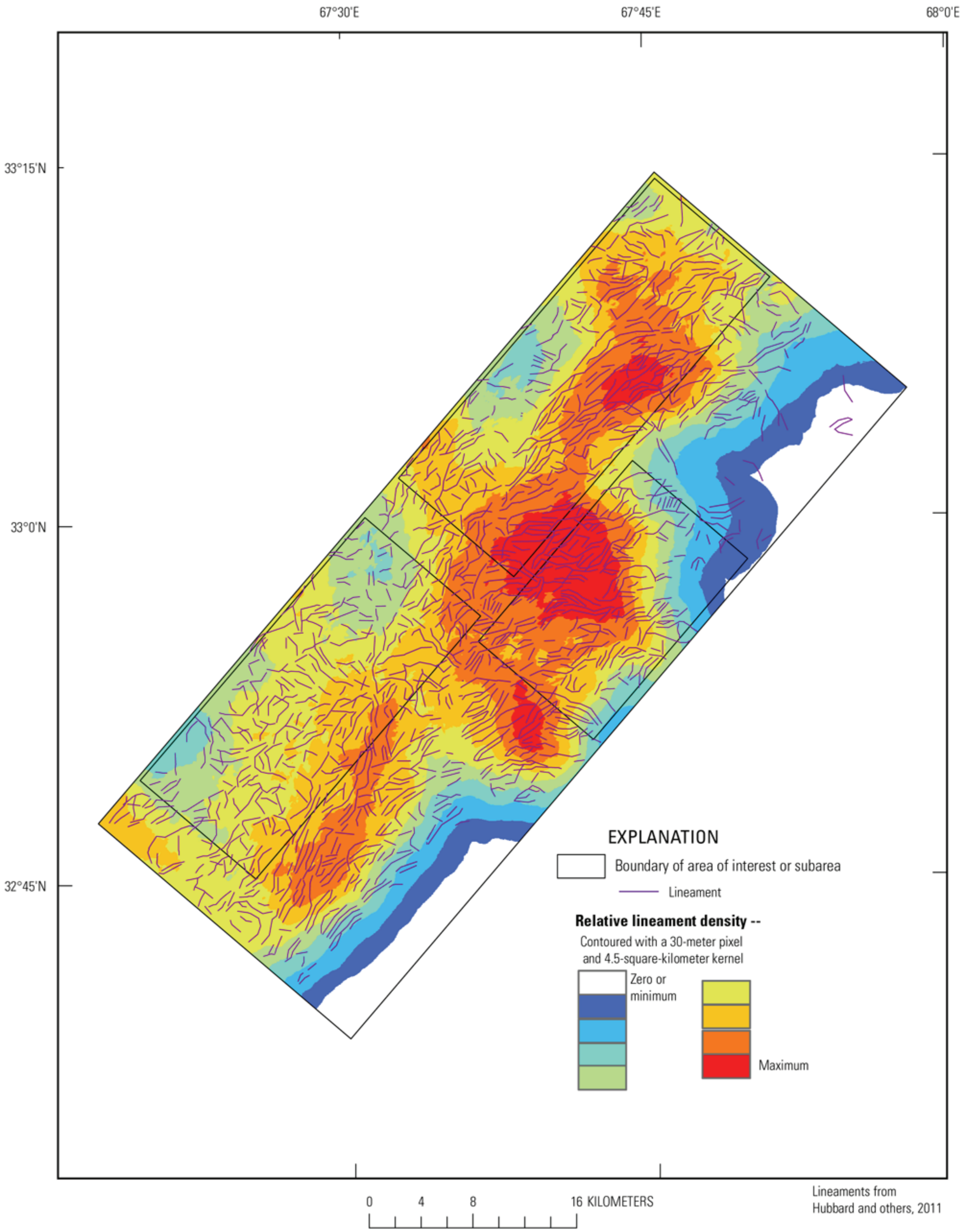


Figure 15C–7. *(a)* Lineaments and lineament density based on 30-meter multispectral Landsat imagery, and *(b)* lineaments and lineament density based on 15-meter multispectral Landsat imagery in the Zarkashan copper and gold area of interest in southeastern Afghanistan.

Although there are few (38) community supply wells installed by nongovernmental organizations in the AOI, there are many more in the settlement of Moqur and in the Tarnak River valley southeast of the AOI. The wells are located in alluvium and are generally tube or dug wells, less than 24 m (meters) deep, with hand pumps that are used to withdraw water for domestic consumption. The shallow groundwater is probably recharged by seasonal flow in the Tarnak River and in the ephemeral streams. The supply wells in the AOI are generally concentrated along ephemeral streams. The water supply to these wells is also probably recharged by seasonal flow in the streams. The amount of water available in these areas depends on the thickness and areal extent of the alluvial deposits. In some valleys these sediments may be more than 400 m thick and may represent areas of considerable stored groundwater; however, the quality and sustainability of this resource are unknown.

Information about deep (greater than 100 m) groundwater in the AOI is very limited. The two deep water-supply wells located in Ghazni, in a setting similar to the Tarnak River valley, indicate that a deep alluvial aquifer is present in that area. It is possible that this aquifer may extend to the Tarnak River valley and may provide a groundwater resource adjacent to the AOI. Properly constructed wells in the deeper alluvial aquifer may have the potential to supply water for mining activities; however, because precipitation rates in the area are low, it is likely that deep groundwater is old water that is recharged very slowly. Wells would need to be sited to avoid interference with existing water-supply wells and other natural or manmade water sources such as springs and karezes. There is probably groundwater in the underlying fractured consolidated rocks in the AOI; however, the characteristics of this resource are unknown.

Some areas of the AOI, as indicated by generalized geohydrologic maps and lineament analyses, are likely areas for further exploration for groundwater resources. The quality and sustainability of water resources in the AOI remain to be determined, however. Close monitoring and careful management of potential new surface-water or groundwater withdrawals would help to protect the quantity and quality of the existing supply for current local water uses. Field investigations including geologic mapping, geophysical surveys, and hydraulic well testing are needed to adequately characterize the extent and availability of groundwater resources in the AOI.

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