Chapter 9C. Geohydrologic Summary of the Kharnak-Kanja Mercury Area of Interest

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9C.1 Introduction

This chapter describes the geohydrology of the Kharnak-Kanja mercury area of interest (AOI) in Afghanistan identified by Peters and others (2007) (fig. 9C–1*a*,*b*). The AOI is located in southwest-central Afghanistan in the districts of Day Kundi, Pasaband, Pur Chaman, Taywara, and Chagcharan in Ghor and Farah Provinces (fig. 9C–1*a*,*b*). The Panjshah-Mullayan, Koh-e-Katif Passaband, and Sahebdad-Khanjar subareas occupy 590, 1,384, and 1,290 km^2 (square kilometers), respectively, of the 7,197-km^2 area of the AOI.

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 some 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 (2011), nongovernmental organizations (NGOs), foreign government agencies, and the Afghan government have begun water-resource investigations; however, these activities and the amount of data collected are limited. This report summarizes the satellite imagery and climatic, topographic, geologic, surface-water, and groundwater data available. Geohydrologic inferences are made on the basis of an integrated analysis of these data and an understanding of conditions in other areas of Afghanistan.

9C.1.1 Climate and Vegetation

Climate information for the Kharnak-Kanja mercury 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.

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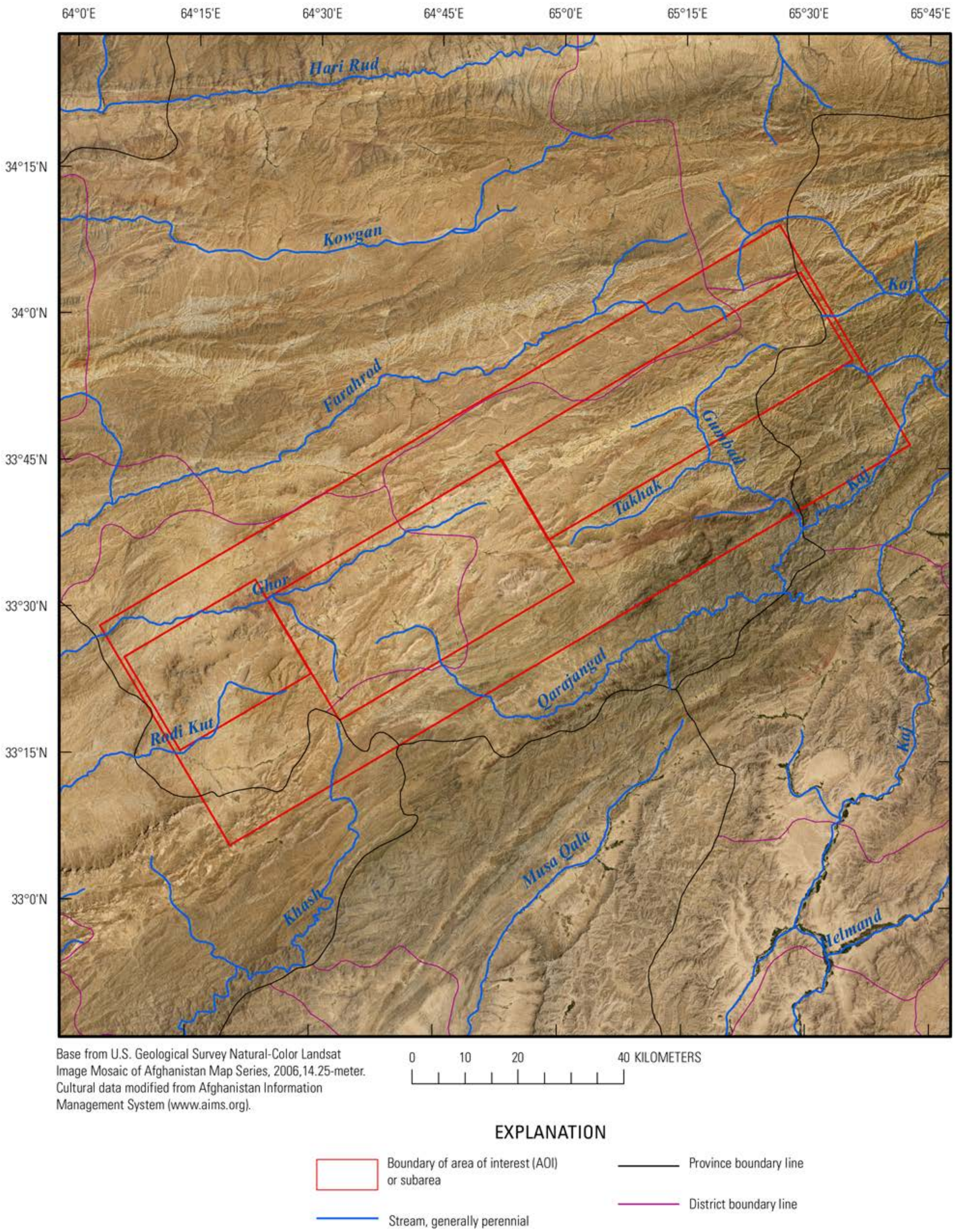

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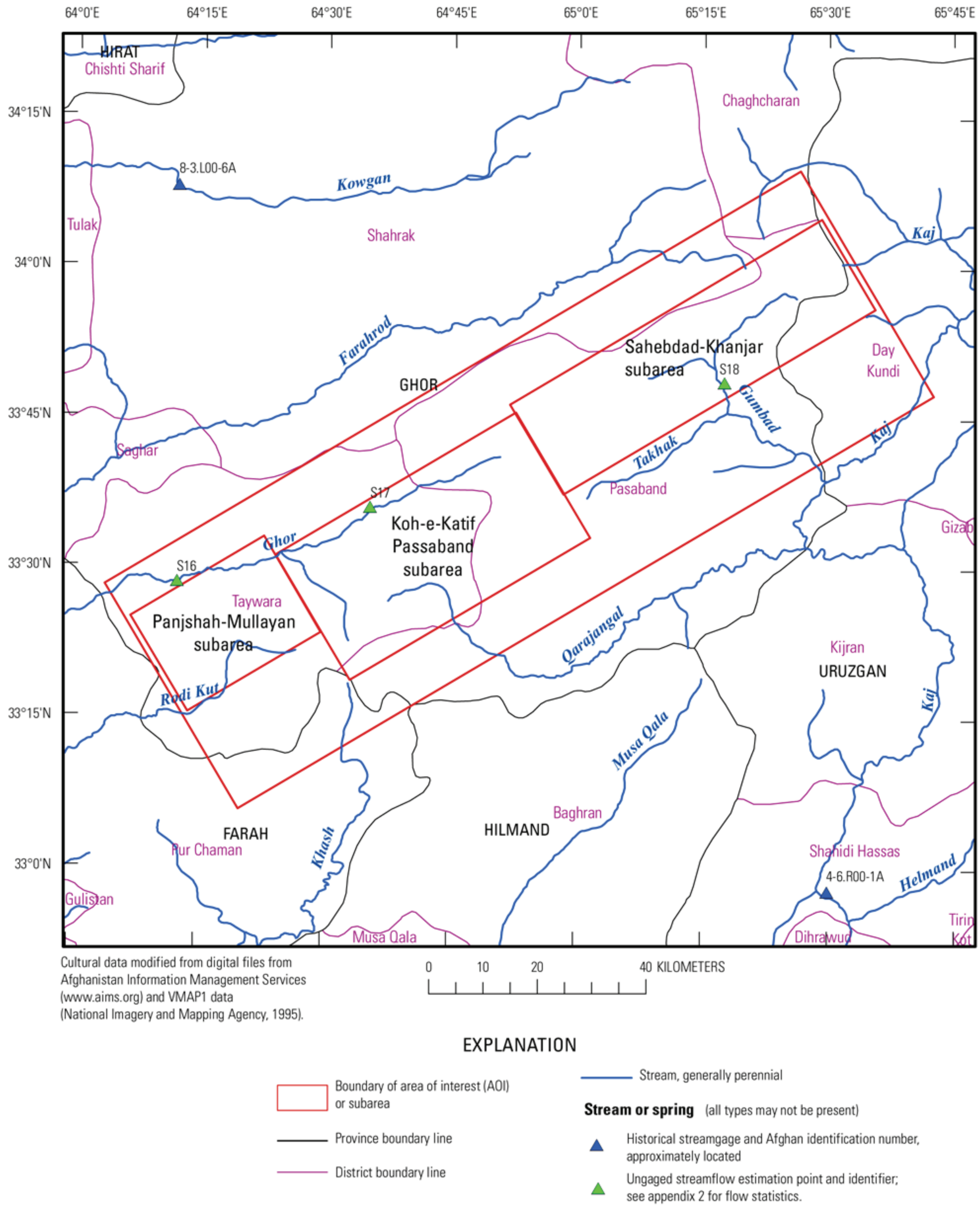

Figure 9C–1. *(a)* Landsat image showing the location of, and *(b)* place names, stream names, and streamgage station numbers in, the Kharnak-Kanja mercury area of interest in Afghanistan.

The observed total precipitation in the AOI for the 2009–2010 water year, as published in the Seasonal Bulletin (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 2), ranged from 201 to 255 mm (millimeters). The AOI received 41 to 60 mm of precipitation in February 2010, the month with the greatest amount of precipitation, with the amount increasing from east to west across the AOI (Ministry of Agriculture, Irrigation, and Livestock, map 3). The AOI received 7 to 33 mm of precipitation in October 2009, the month with the least precipitation, with the amount increasing from west to east (Ministry of Agriculture, Irrigation, and Livestock, map 4).

The Chakhcharan Agromet station is located in Ghor Province approximately 60 km north of the northwest corner of the AOI. This station is the Agromet station that is closest to the AOI for which long-term average (LTA) precipitation data for the 2009–2010 water year are available. Precipitation data for the Chakhcharan Agromet station (Ministry of Agriculture, Irrigation, and Livestock, 2010) are shown in table 9C–1.

Table 9C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation at the Chakhcharan Agrometeorological station 60 kilometers north of the Kharnak-Kanja mercury area of interest, Afghanistan.

[AOI, area of interest; km, kilometers; m, meters; mm, millimeters; °C, degrees Celsius; nr, not reported]

Agromet Station	Distance from AOI center (km)	Elevation (m)	Precipitation				Temperature		
				Long-term average[1]			Long-term average[1]		
			2009–2010 annual (mm)	Annual (mm)	Monthly minimum and month (mm)	Monthly maximum and month (mm)	Minimum and month (°C)	Monthly mean (°C)	Maximum and month (°C)
Chakhcharan	60	2,250	199.9	186.7	0 August–September	42.5 April	nr	nr	nr

[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).

The Chakhcharan Agromet station had a total of 11 reported snow days during the 2009–2010 water year, distributed as follows: November 2009, 2 days; December 2009, 3 days; January 2010, 2 days; and February 2010, 4 days. The snowfall reported at this station for the 2009–2010 water year was 58.6 cm (centimeters). The snow-depth map for 17 January, 2010 (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 6), indicates that snow depth in the AOI was between 2 and 10 cm in January 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 vegetation in the AOI is mostly alpine vegetation classified by Breckle (2007, p. 161) as "thorny cushions, subalpine and alpine deserts and meadows." Much of the upland surface of the AOI is bedrock outcrop with thin alluvial cover. Azonal riverine vegetation likely was present in the stream valleys, but the trees have been harvested for fuel and building materials. Most land suitable for farming has been plowed and planted, especially along major stream valleys and some of the ephemeral tributary stream valleys. Irrigated fields are present in many of the valleys in the AOI (fig. 9C–2).

9C.1.2 Demographics

The Kharnak-Kanja mercury AOI is sparsely populated, with most areas having 1 to 5 inhabitants per square kilometer as mapped by LandScan (Oak Ridge National Laboratory, 2010) (fig. 9C–3). A few areas have no inhabitants, as indicated by the gray shading in figure 9C–3. The wider stream valleys are more densely populated, but the maximum population rarely exceeds the 51 to

100/km² category. Most areas along narrower stream valleys are sparsely populated. The population density shown in figure 9C–3 has a pixel resolution of about 1 km² (Oak Ridge National Laboratory, 2010).

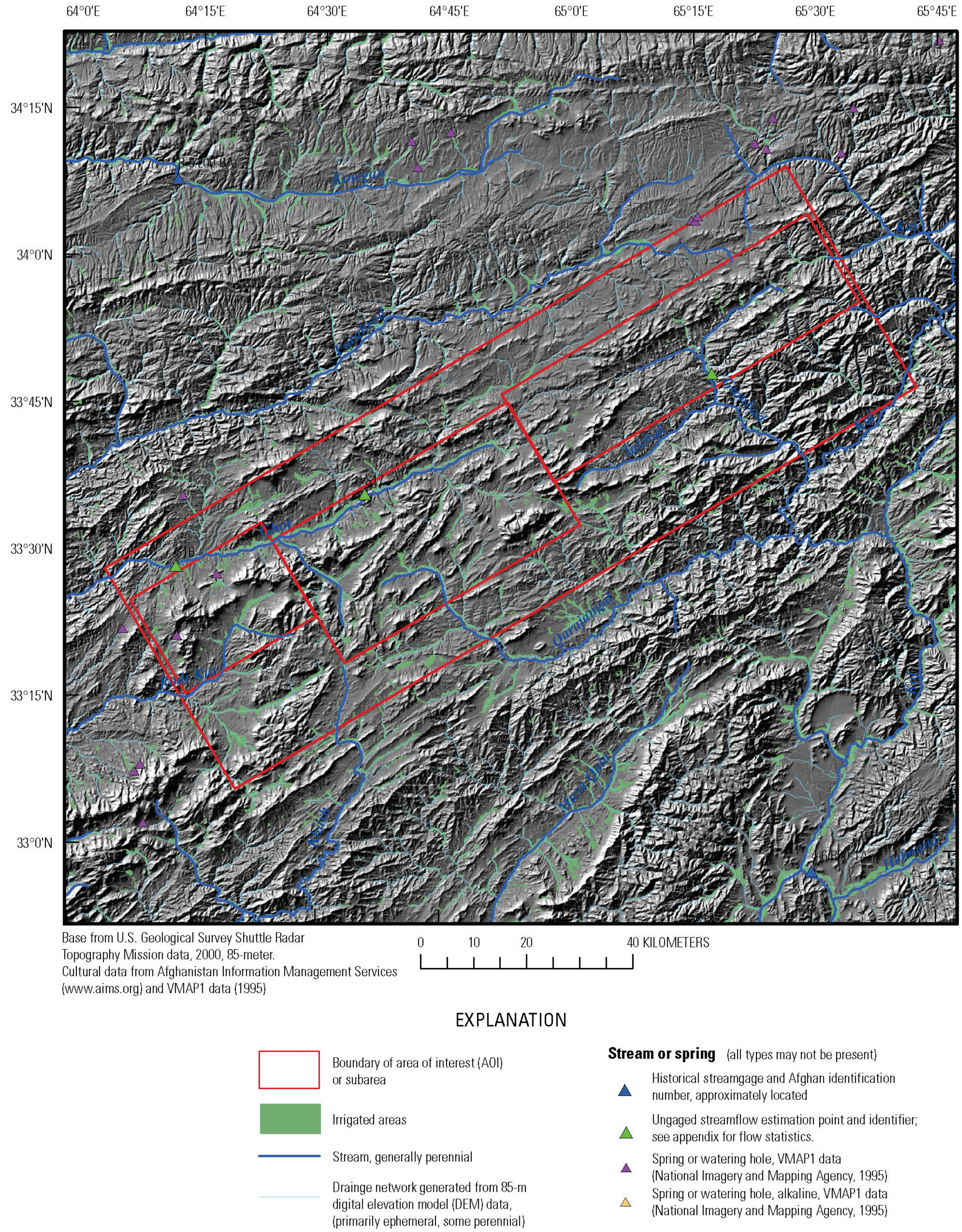

Figure 9C–2. Historical streamgage locations, digitally generated drainage network, and irrigated areas in the Kharnak-Kanja mercury area of interest in Afghanistan.

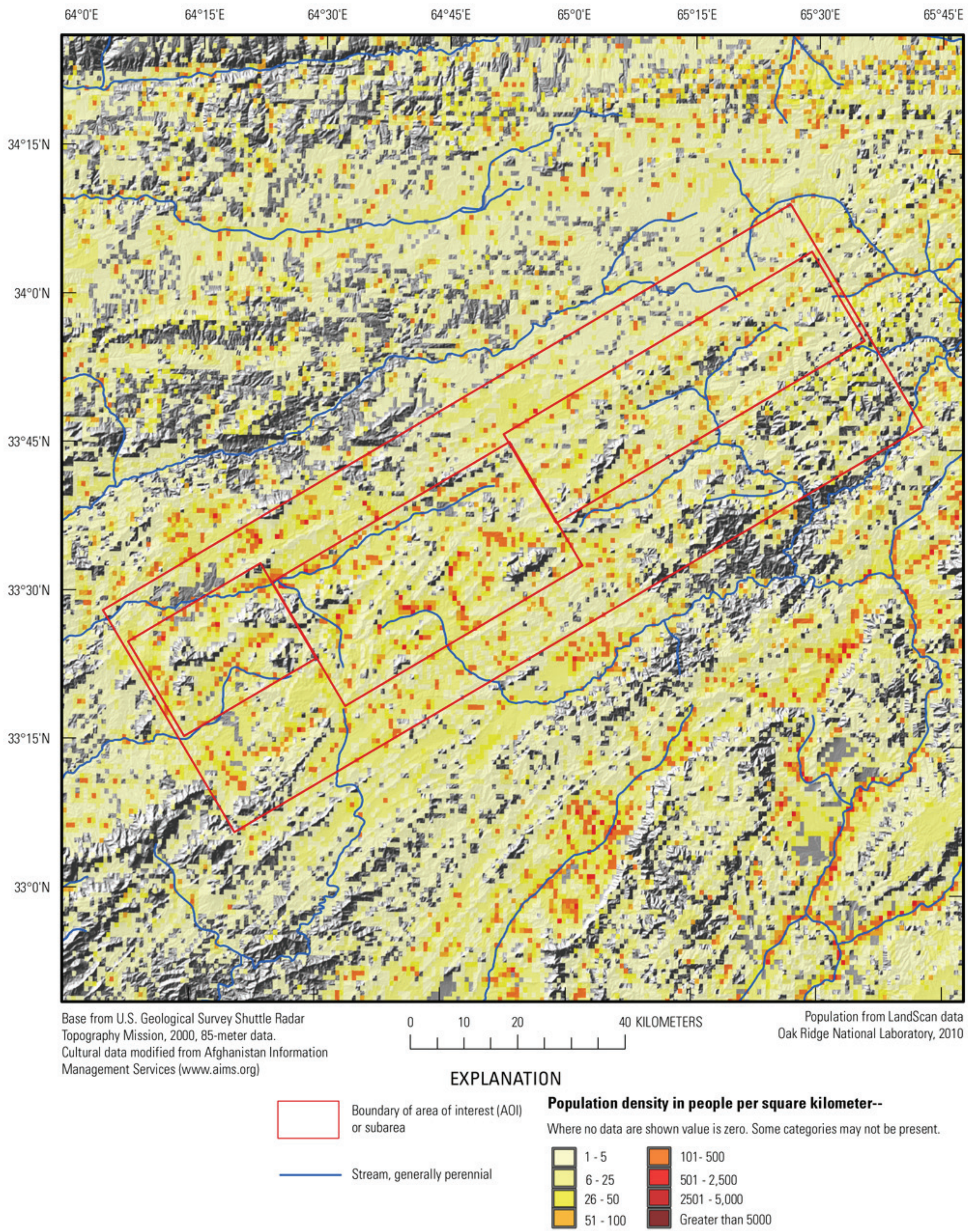

Figure 9C–3. Population density of the Kharnak-Kanja mercury area of interest in Afghanistan.

9C.1.3 Topography

The topography of the Kharnak-Kanja mercury AOI is mountainous with east-northeast-trending ridges and valleys (Davis, 2006) (fig. 9C–4). The elevations of the valleys average 2,200 m (meters) above sea level (asl) and the elevations of the ridges average 3,000 m asl, with some peaks exceeding 3,500 m asl (Bohannon, 2005). Two long valleys that characterize the AOI are those of the Ghor River, about 75 km long, in the western area of the AOI, and the Takhak River, about 30 km long, just south of the Sahebda-Khanjar subarea (fig. 9C–2).

9C.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 Kharnak-Kanja mercury AOI is in the "Central Afghanistan Hydrogeological Folded Region that occupies the central part of the country with a predominantly mountain climate." The outcrops in the AOI can be grouped according to their physical and hydraulic properties. The generalized geohydrology of the AOI is shown in figure 9C–4 with the underlying topography to allow examination of the geohydrology in the context of relief. Figure 9C–5*a*,*b* shows 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 figure 9C–5*a*,*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 the AOI, ranked from high to low relative hydraulic conductivity (Freeze and Cherry, 1979, table 2.3), are "conglomerate sediments and rocks; limestones and dolostones; sedimentary rocks; metamorphic rocks; and intrusive rocks and lavas" (figs. 9C–4 and 9C–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 McKinney and others (2005).

9C.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), in the Kharnak-Kanja mercury AOI is shown in figure 9C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), also is shown in figure 9C–2. National Imagery and Mapping Agency (1995) Vector Map (VMAP1) mapped springs are also shown in and adjacent to the AOI. Names of major streams and identification numbers of any streamgages and ungaged streamflow estimation sites in the AOI are shown in figure 9C–1*b*.

The streamgage nearest to the AOI, located about 80 km northwest of the center of the AOI, is the Kowgan River at Tangi Azu (Afghan identification number 8–3.L00–6A) (figs. 9C–1*b* and 9C–2). This station is at an elevation of 2,200 m asl and has a drainage area of 2,030 km^2 and a period of record that extends from 16 October, 1962, to 30 September, 1978 (Williams-Sether, 2008). The mean annual streamflow per unit area for this station is about 0.0009 $m^3/s/km^2$ (cubic meters per second per square kilometer). The seasonal timing of maximum and minimum monthly streamflow is high flows in the spring and low flows in fall. A statistical summary of monthly and annual mean streamflows for this station is presented in table 9C–2. Statistical summaries of streamflow data for all available historical gages in Afghanistan can be accessed at *http://afghanistan.cr.usgs.gov/water.php*.

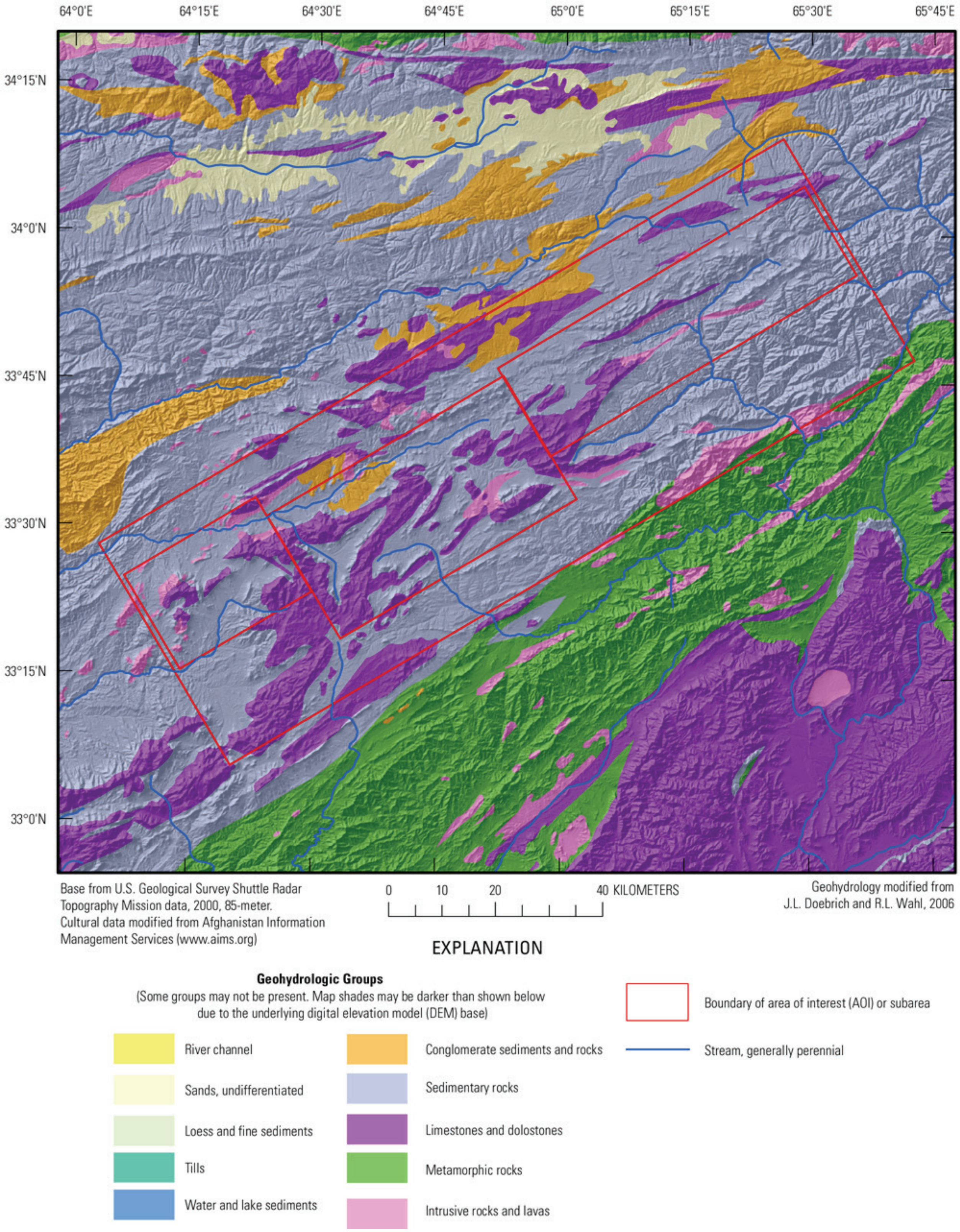

Figure 9C–4. Topography and generalized geohydrology of the Kharnak-Kanja mercury area of interest in Afghanistan.

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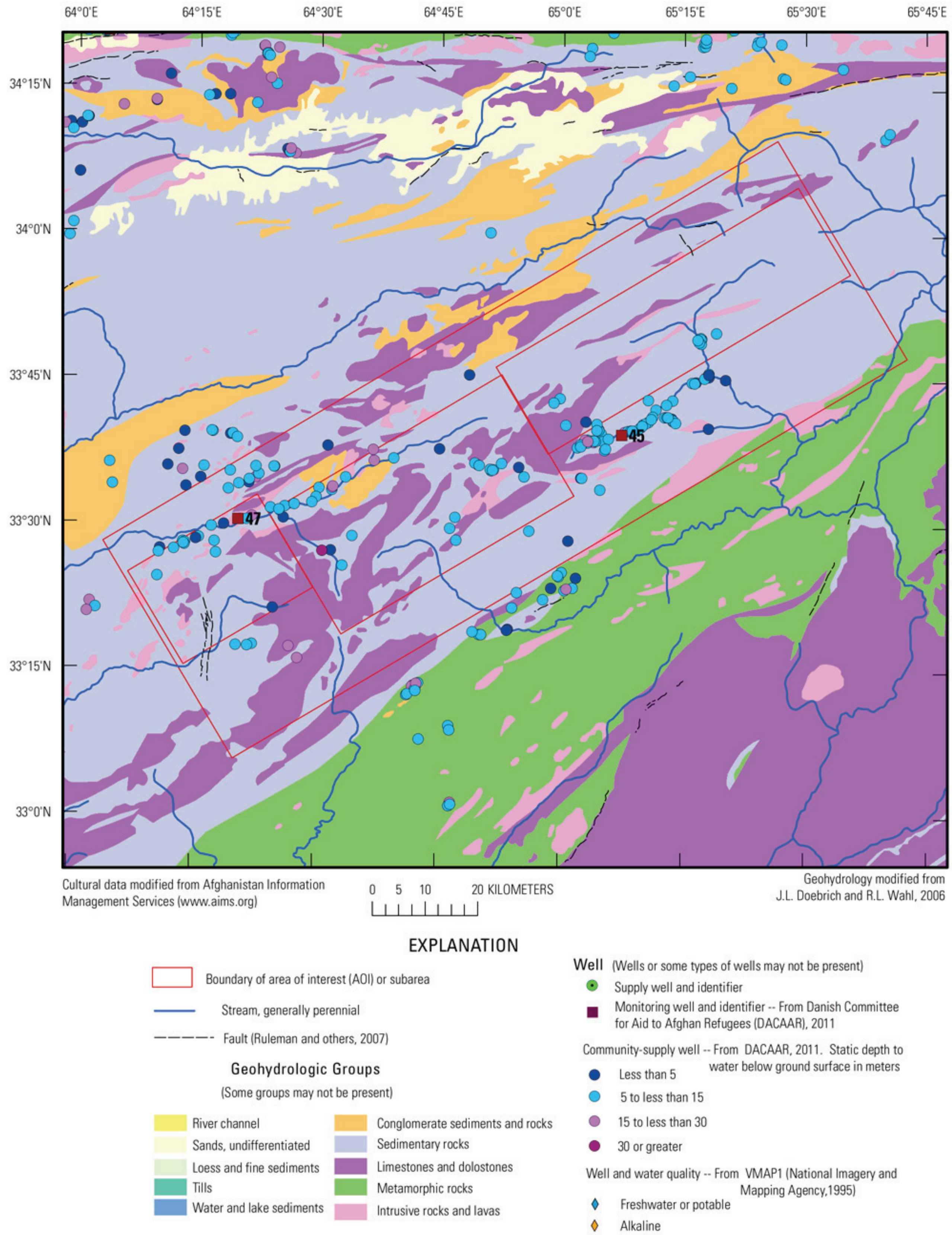
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45
47
Cultural data modified from Afghanistan Information Management Services (www.aims.org)
0 5 10 20 KILOMETERS
Geohydrology modified from J.L. Doebrich and R.L. Wahl, 2006
EXPLANATION
Boundary of area of interest (AOI) or subarea
Stream, generally 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

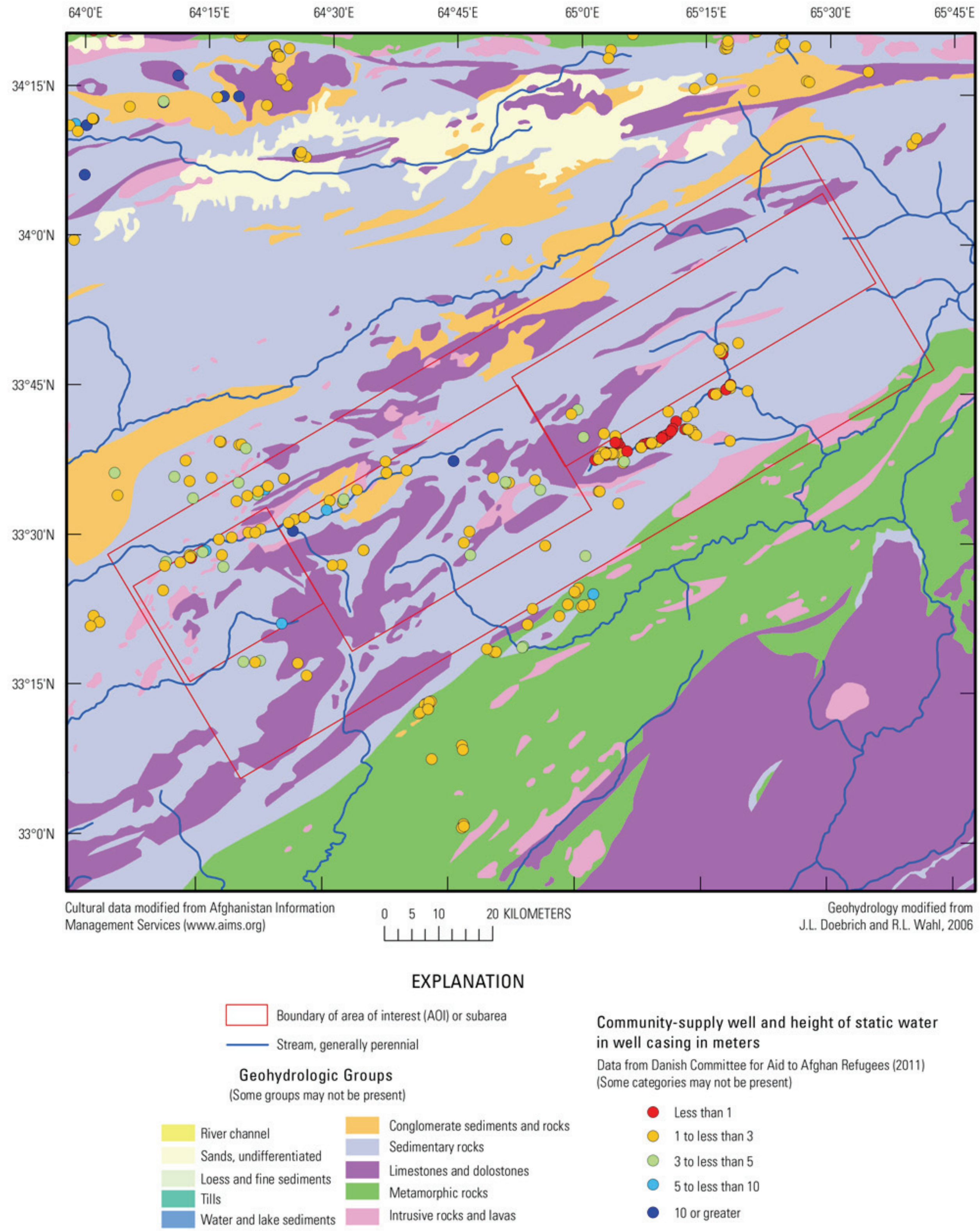

Figure 9C–5. (*a*) Generalized geohydrology, mapped faults, well locations, and depth to water, and (*b*) geohydrology and height of static water in well casings in community supply wells in the Kharnak-Kanja mercury area of interest in Afghanistan.

Table 9C–2. Statistical summary of monthly and annual mean streamflows for the Kowgan River at Tangi Azu 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	1.62	1966	0.44	1971	0.79	0.36	0.46	3.54
November	1.49	1966	0.38	1970	0.84	0.36	0.43	3.76
December	1.60	1970	0.32	1971	0.86	0.34	0.39	3.86
January	1.47	1965	0.24	1971	0.81	0.35	0.43	3.64
February	2.29	1965	0.29	1971	0.90	0.54	0.60	4.04
March	8.36	1969	0.61	1967	3.15	2.29	0.73	14.2
April	17.7	1975	1.03	1971	6.99	5.12	0.73	31.5
May	9.84	1975	0.38	1971	4.54	3.18	0.70	20.4
June	3.78	1975	0.36	1971	1.39	1.08	0.78	6.24
July	1.38	1975	0.34	1978	0.64	0.29	0.44	2.88
August	1.22	1975	0.30	1978	0.62	0.25	0.41	2.78
September	1.58	1975	0.38	1978	0.71	0.35	0.50	3.20
Annual	**3.43**	**1965**	**0.52**	**1971**	**1.90**	**0.96**	**0.50**	**100**

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 S16, S17, and S18 (figs. 9C–1*b* and 9C–2) on selected streams in the AOI or subareas, using a drainage-area-ratio method (Olson and Mack, 2011) based on historical flows at the Lal River at Shinya streamgage station (Afghan identification number: 8–11.L00–1A) (Olson and Williams-Sether, 2010). The Lal River at Shinya streamgage station was selected as the most representative historical gage, based on drainage-area size and location, for use with this method. The estimated mean annual streamflow for point S16 (app. 2), with a drainage area of 2,390 km^2, is about 7.39 m^3/s (cubic meters per second). By applying the same method, the estimated mean annual streamflows at points S17 and S18 are 3.52 and 1.32 m^3/s, respectively. The seasonal timing of maximum and minimum monthly streamflow, with high flows in the spring to early summer and low flows in late fall and winter (app. 2), probably is similar to that at the Lal River at Shinya station.

9C.2.2 Groundwater

Approximately 190 shallow community groundwater-supply wells are known to have been installed in the Kharnak-Kanja mercury AOI by NGOs. Information about these wells can be found in a database maintained by DACAAR (Danish Committee for Aid to Afghan Refugees, 2011). Well-depth and static-water-level information is available for most of the wells in this database (figs. 9C–5*a*,*b*). All but one of the supply wells are less than 30 m deep; one well is 33 m deep. The median well depth is 10 m. The depth to water in 89 percent of the supply wells in the AOI is less than 15 m (fig. 9C–5*a*). The median depth to water is 8 m.

Available well-construction information is limited; however, some wells may be “tube” wells (driven wells with polyvinyl chloride (PVC) casing) but at least 130 (68 percent) are described as dug wells with concrete-ring casing. Wells are generally installed in unconsolidated sediments, completed a few meters below the depth at which water is first encountered, and equipped with a hand pump. Figure 9C–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 is 1.6 m and 20 percent of the wells for which information is available have less than 1 m of static water. Such shallow wells 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). This condition is particularly evident in the Takhak River valley just south of the Sahebdad-Khanjar subarea (fig. 9C–5*b*). Any new groundwater withdrawals in this area would need to be closely monitored to avoid adversely affecting existing wells.

Two groundwater-monitoring wells (GWMs) in the AOI, GWM 45 and 47 (fig. 9C–5*a*), are monitored by DACAAR for groundwater levels and specific conductance. Hydrographs of water levels in GWMs, 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° Celsius (µS/cm), and depth to water in meters below ground surface (bgs). The GWMs likely are generally constructed in alluvial material. The hydrograph for GWM 45 indicates a seasonal water-level range of 3 to 4 m. GWM 47 indicates a seasonal water-level range that increased from 2 to 4 m over the period of record (2005–2008). These measured water-level fluctuations indicate that many shallow dug wells may be vulnerable to becoming dry, and any new groundwater withdrawals in this area would need to be closely monitored to avoid dewatering existing wells. The monitoring-well hydrographs show an annual water-level peak in April and a minimum in December that are similar to the pattern of estimated streamflows. Streamflow was relatively low during the summer months, whereas groundwater levels declined throughout the summer months. This gradual groundwater-level recession may indicate that considerable groundwater flows from surrounding sedimentary bedrock mountains to the valley bottoms, where wells are located (figs. 9C–4 and 9C–5*a*). The specific conductance in both monitoring wells is about 700 µS/cm, indicating a slightly elevated dissolved-solids content relative to that in some valley-fill aquifers. The specific conductance decreases 100 to 200 µS/cm during the peak-water-level periods, indicating that water with a low dissolved-solids content is recharging the groundwater during spring melting periods.

9C.2.3 Lineament Analyses

Lineaments are photolinear features that may result from the presence of underlying zones of high-angle bedrock fractures, fracture zones, faults, or bedding-plane weaknesses. Lineament analyses of the Kharnak-Kanja mercury AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, U.S. Geological Survey, August 24, 2011, written commun.) were conducted using DEM and natural-color satellite imagery (fig. 9C–6) and Advanced Spaceborne Thermal Emission and Reflection Radiometry (ASTER) satellite imagery (fig. 9C–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 9C–6 were delineated visually, whereas those in figure 9C–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, U.S. Geological Survey, August 24, 2011, written commun.). 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, such as the southwest part of the Koh-e-Katif Passaband subarea (figs. 9C–6 and 9C–7*a*,*b*), are areas where bedrock fractures may be 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. Areas where lineament density is high in carbonate rocks (fig. 9C–5) may be areas with solution-weathered fracture zones. Many lineaments in the AOI are parallel to bedding structure, indicating possible bedding-plane weaknesses. Some lineaments follow drainage patterns that cross the bedding structure, indicating a possible fracture network orthogonal to bedding planes. 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.

9C.3 Summary and Conclusions

Water resources are more likely to be available for mining and other uses in the Kharnak-Kanja mercury area of interest (AOI) than in other areas of Afghanistan. Water resources in the AOI and surrounding area include both surface water and groundwater. Shallow alluvial aquifers in the valley bottoms of the AOI are likely a highly utilized groundwater resource. Wells in the AOI are primarily shallow dug wells that may be susceptible to becoming dry during periods of low recharge or with increasing water use. Most streams may also be highly utilized by the local population as the primary source of water for irrigation. The diversion of water from the rivers to support mining activities would need to be closely monitored, particularly during low-flow periods, if the quantity and quality of the water resource are to be preserved so that surface-water flow remains sufficient to supply water for irrigation and to provide recharge to the aquifers that supply groundwater to the shallow wells for domestic consumption.

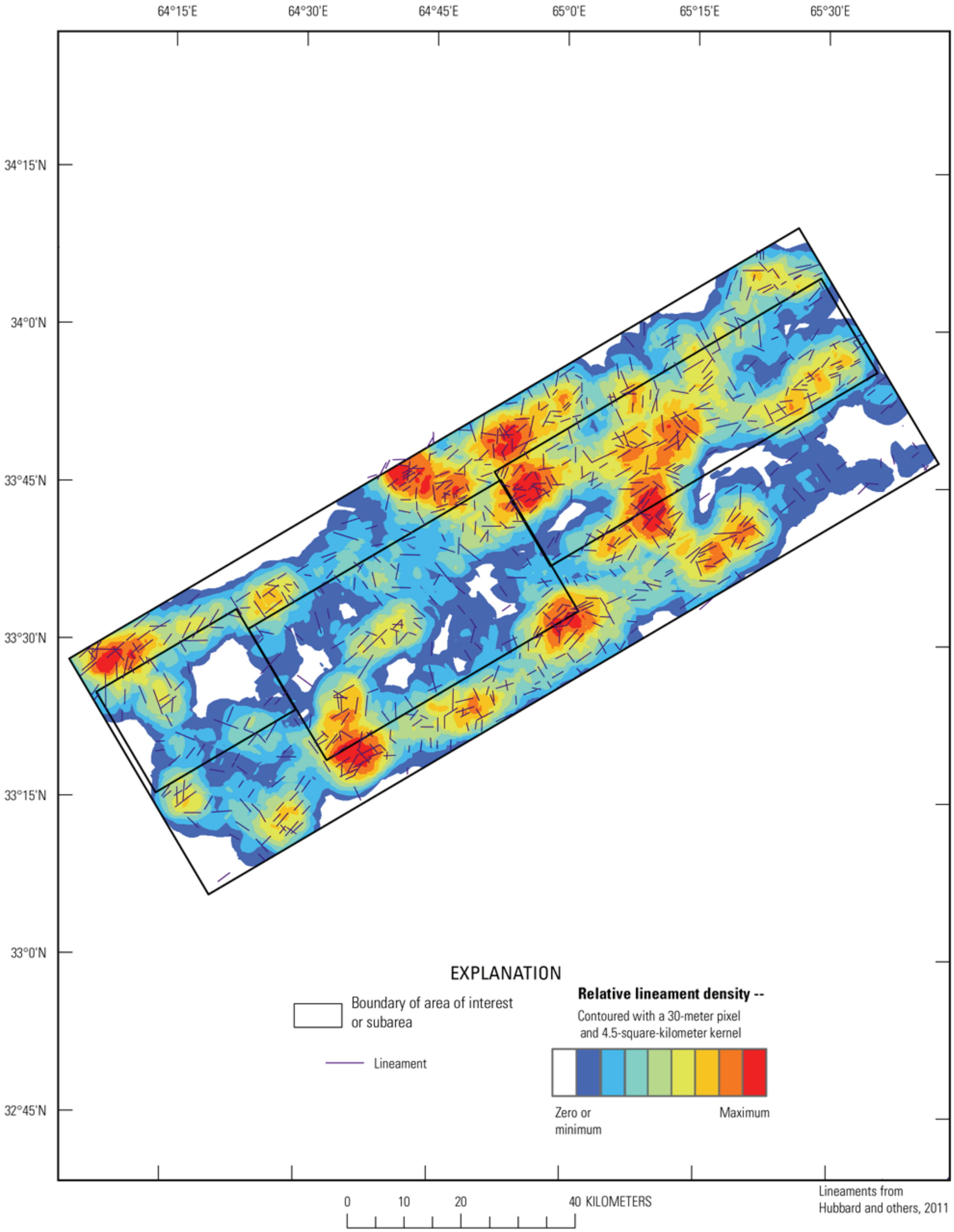

Figure 9C–6. (on previous page) Lineaments and lineament density based on 30-meter digital-elevation-model data and natural-color Landsat imagery in the Kharnak-Kanja mercury area of interest in Afghanistan.

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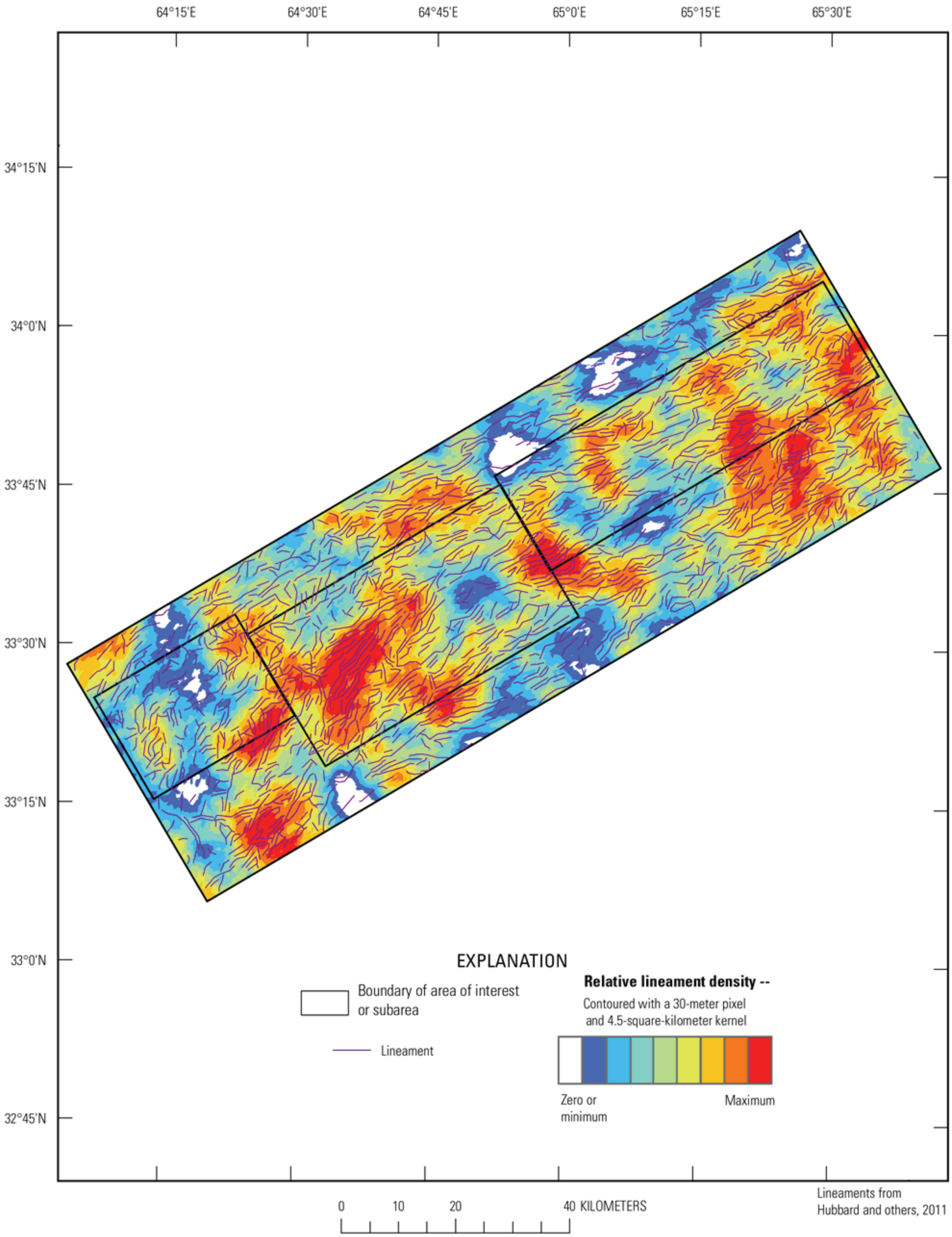
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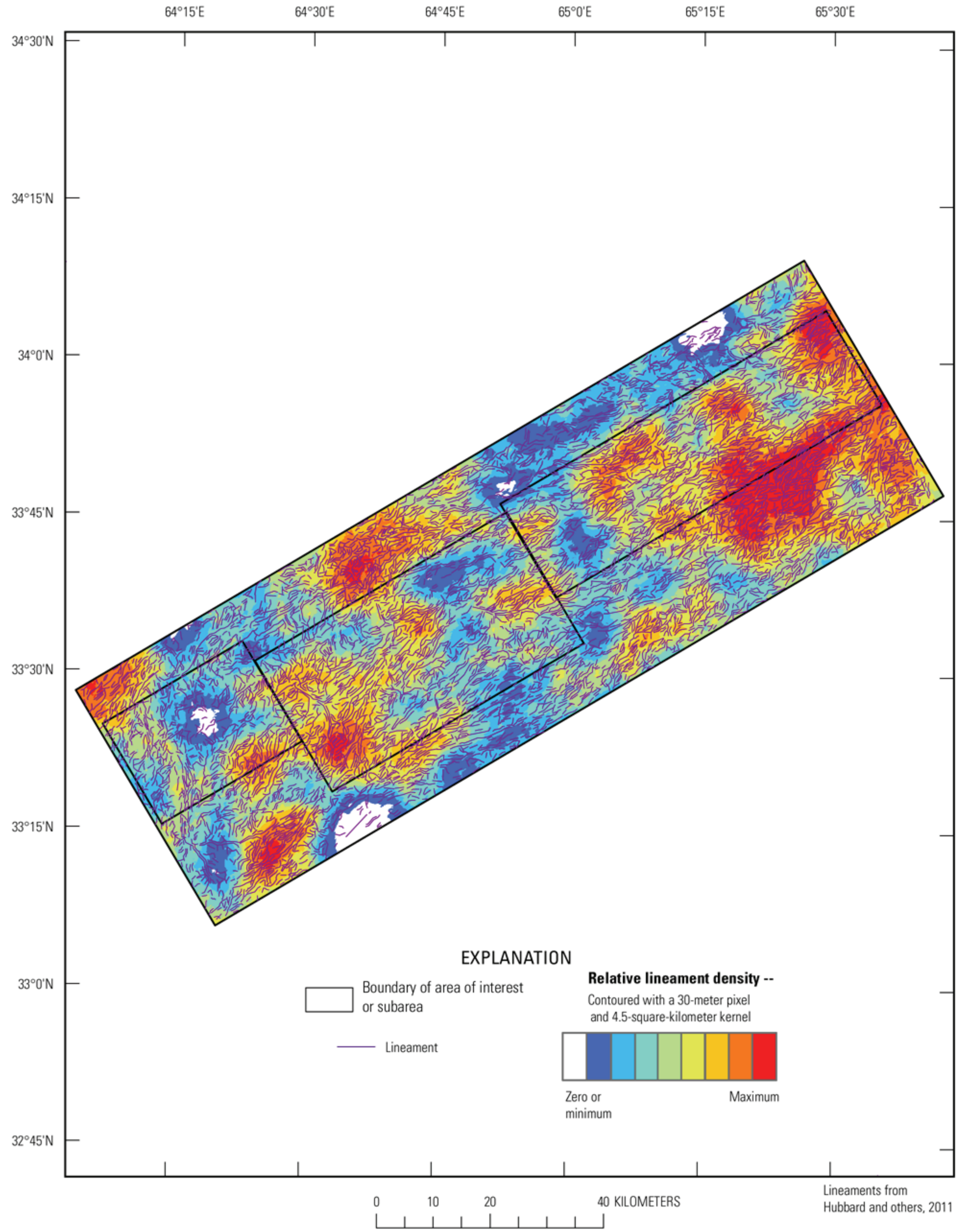
33°15'N
33°0'N
32°45'N
EXPLANATION
Boundary of area of interest or subarea
Lineament
Relative lineament density --
Contoured with a 30-meter pixel and 4.5-square-kilometer kernel
Zero or minimum
Maximum
0
10
20
40 KILOMETERS
Lineaments from Hubbard and others, 2011

b



b

Figure 9C–7. (on previous pages) *(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 Kharnak-Kanja mercury area of interest in Afghanistan.

No information about bedrock groundwater resources in the AOI or adjacent areas is available. Sedimentary bedrock in the AOI may represent a potentially available source of groundwater. 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, the limited information available indicates a slightly elevated dissolved-solids content in the groundwater in some valley-fill aquifers. 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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