

Chapter 21C. Geohydrologic Summary of the Khanneshin Carbonatite Area of Interest

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21C.1 Introduction

This chapter describes the geohydrology of the Khanneshin carbonatite area of interest (AOI) in Afghanistan identified by Peters and others (2007). The AOI occupies 7,771 km² (square kilometers) and is located primarily in the Dishu, Garmser, and Reg Districts of Helmand Province (fig. 21C–1*a,b*). A small area of the northwestern most part of the AOI, about 20 km², is in the Chahar Burja District of Nimroz Province. The Khanneshin volcano is a topographic high formed by extrusive volcanic rocks in the center of the AOI (fig. 21C–1*a*). The Khanneshin volcano is approximately 9.5 km (kilometers) south of the Helmand River. The AOI is in the western part of the Registan (land of sand), an area that is characterized by active dunes (Whitney, 2006). Lashkar Gah, the Helmand Province center, is approximately 130 km northeast 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. 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.

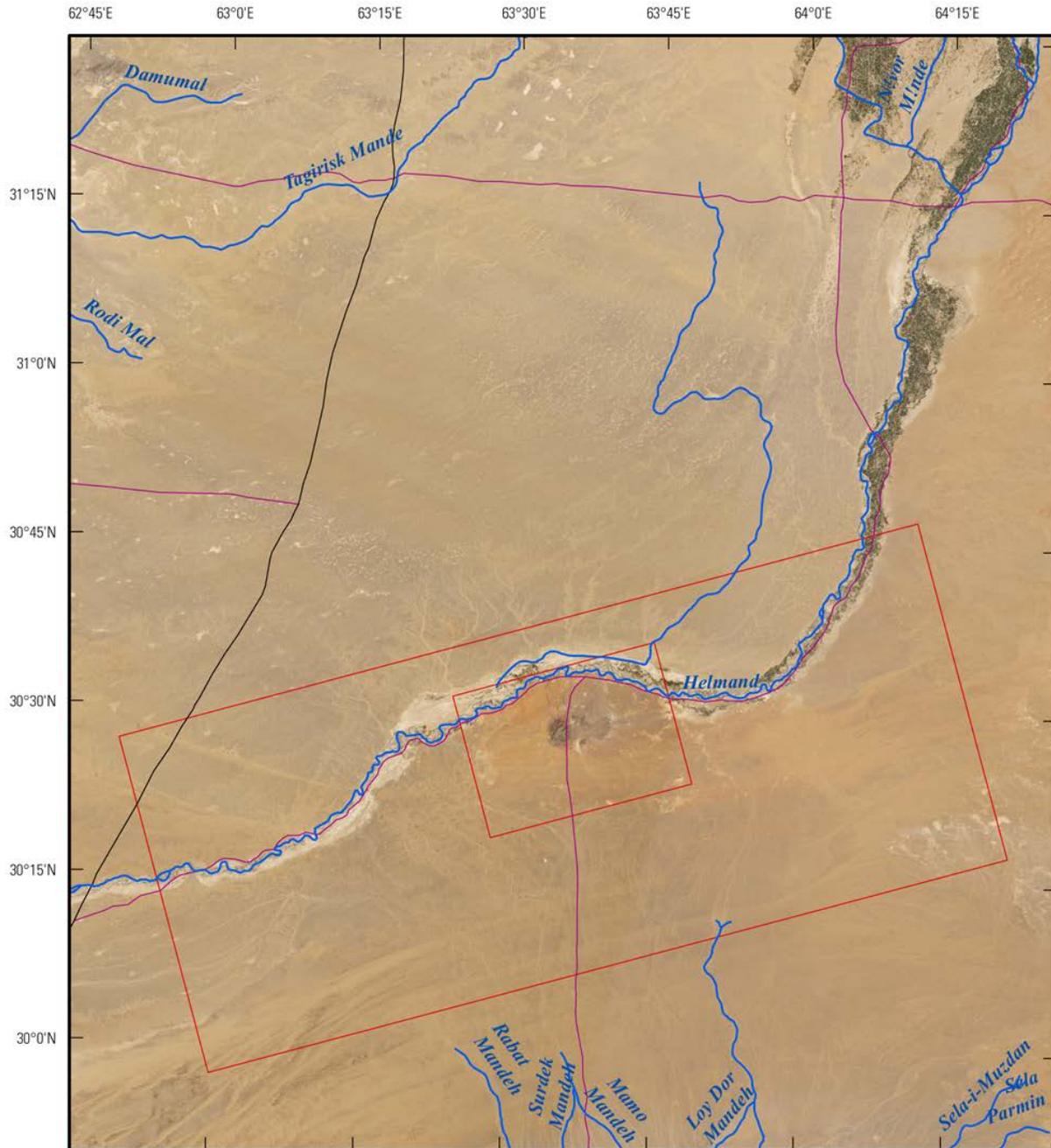
Afghanistan's recent turbulent history has left many of the traditional archival institutions in ruins, and most water-resource and meteorological data-collection activities had stopped by 1980. Recently, nongovernmental organizations (NGOs), foreign government agencies, and the Afghan government have begun water-resource investigations, and U.S. Geological Survey (USGS) minerals teams conducted field reconnaissance work in the AOI in September 2009, and again in August 2010; 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.

21C.2 Climate and Vegetation

Climate information for the Khanneshin carbonatite 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 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). 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



Base from U.S. Geological Survey Natural-Color Landsat Image Mosaic of Afghanistan Map Series, 2006, 14.25-meter. Cultural data modified from Afghanistan Information Management System (www.aims.org).



EXPLANATION

- Boundary of area of interest (AOI) or subarea
- Province boundary line
- District boundary line
- Stream, generally perennial

b

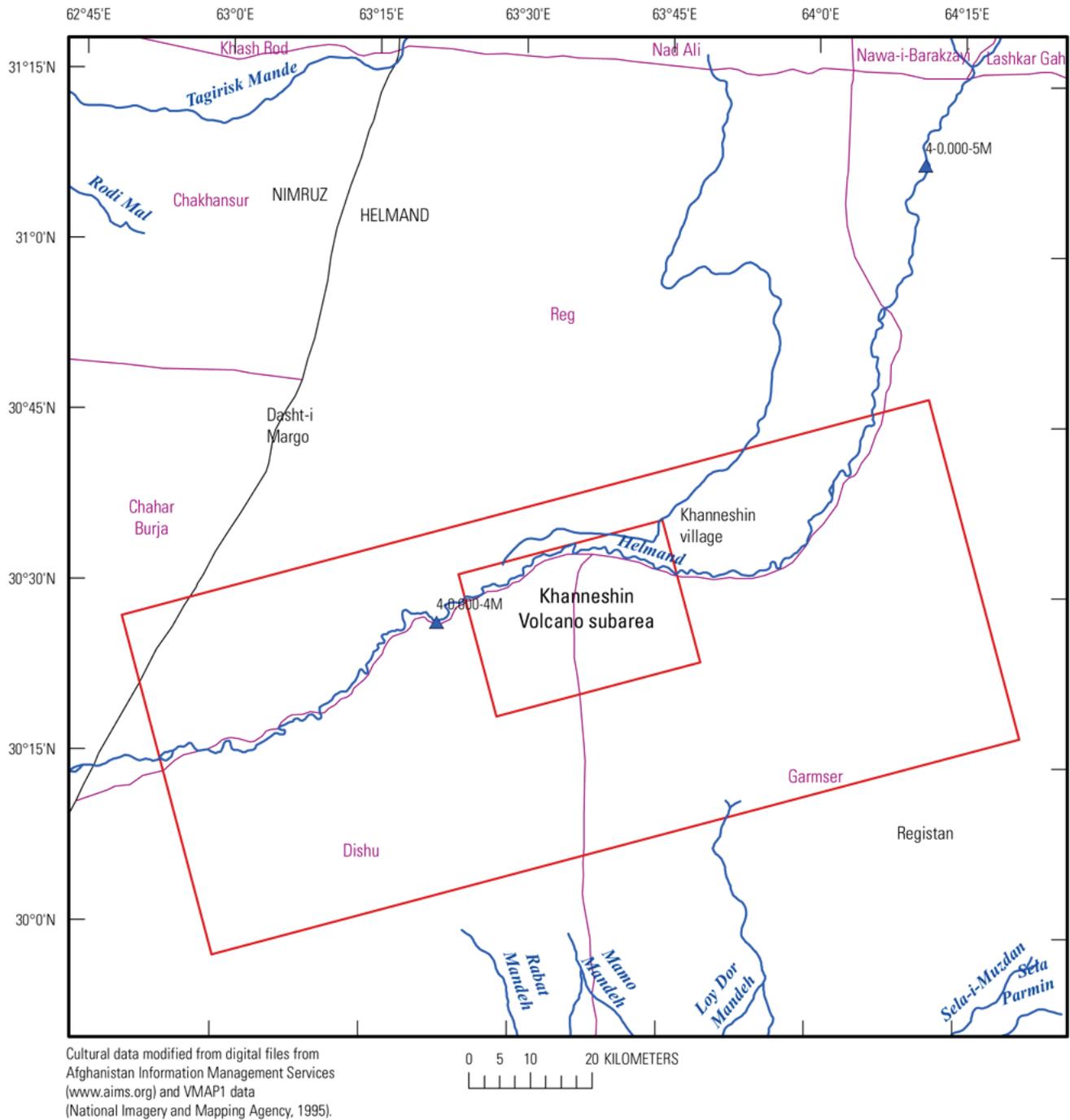


Figure 21C-1. (a) Landsat image showing the location of, and (b) place names, stream names, and streamgage station numbers in, the Khanneshin carbonatite area of interest in southern Afghanistan.

The 2009–2010 water year average precipitation recorded at a number of stations in Agromet’s South Region was 177.8 mm (millimeters) (Ministry of Agriculture, Irrigation, and Livestock, 2010). The average precipitation for the four Agromet stations located in Helmand Province was 172 mm/yr (millimeters per year). The station at Zaranj in Nimroz Province, approximately 172 km west-northwest of the AOI, recorded 41 mm of precipitation during the 2009–2010 water year (Ministry of Agriculture, Irrigation, and Livestock, 2010). The prevailing wind direction in this part of Afghanistan is northwest to southeast, and then becomes west to east over the AOI (Whitney, 2006). The amount of precipitation at Zaranj is probably indicative of the precipitation in the AOI.

A climate diagram presented by Whitney (2006, fig. 10) for Deshu (Dishu), a historical meteorological station about 29 km west of the AOI near the Helmand River with a total of 4 years of record prior to 1973, shows an average precipitation of 73 mm and an average temperature of 20.9 °C (degrees Celsius). The maximum temperature recorded at the Zaranj Agromet station in July 2010 was 47.6 °C (Ministry of Agriculture, Irrigation, and Livestock, 2010). This was also the maximum temperature recorded during the 2009–2010 water year for the South Region (Ministry of Agriculture, Irrigation, and Livestock, 2010). The minimum temperature recorded at Zaranj in July 2010 was 23 °C (Ministry of Agriculture, Irrigation, and Livestock, 2010). The Agromet station at Kandahar (table 21C–1), about 240 km northeast of the AOI, is the closest Agromet station for which both 2009–2010 water year and long-term average (LTA) precipitation and temperature data are available (Ministry of Agriculture, Irrigation, and Livestock, 2010). The 2009–2010 average monthly high temperature at Kandahar was 33.37 °C in July 2010 and the average monthly low temperature was 9.29 °C in December 2009. The LTA high temperature was 31.8 °C for July and the LTA low temperature was 4.8 °C for January.

Evaporation rates were measured at pan evaporation sites in southern Afghanistan in 1964. The evaporation rate at Lashkar Gha (fig. 21C–1b), the closest site to the AOI, was 2.8 m/yr (meters per year) (Whitney, 2006). As is common in desert environments, the evaporation rates are much greater than the precipitation rates.

The area within the flood plain of the Helmand River is extensively irrigated and agriculturally developed (fig. 21C–2). Native vegetation in the AOI is sparse and is dominated by desert shrubs, bushes, and grasses. On upland bedrock surfaces of the Khanneshin volcano, plants grow in fractures in the volcanic rocks (fig. 21C–3). Desert plants are also present in places where soil or sediments overlie the bedrock, such as in ephemeral stream channels and at bedrock-alluvium contacts. The plants that grow in the ephemeral stream channels likely have access to an abundant supply of water throughout the year. This water supply is indicated by plants in ephemeral stream channels that show active growth, such as green foliage, whereas plants outside the channels are dormant. The vegetation in the desert plain surrounding the volcanic cone is sparse. The active dune fields are devoid of vegetation.

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) depicts two vegetation zones in the AOI. The *Calligonum-Aristida*-Sanddesert type vegetation is dominant in the AOI. *Haloxylon salicornicum*-Desert type vegetation is present in the extreme eastern and western parts of the AOI. Breckle (2007) states “The deserts of the north, west and south in the Registan and Dasht-i Margo contain active sand dune areas and dunes fixed by a rather open vegetation. The flora here is scarcely modified by man.”

Table 21C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation and temperature at the Kandahar Agrometeorological (Agromet) station located 240 km northeast of the Khanneshin carbonatite 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				Temperature			
			2009–2010 annual (mm)	Long-term average ¹			Long-term average ¹			
				Annual (mm)	Monthly minimum and month (mm)	Monthly maximum and month (mm)	Minimum and month (°C)	Monthly mean (°C)	Maximum and month (°C)	
Kandahar	240	1,020	166	155.5	0 September June	49.1 January	4.8 January	15.9	31.8 July	

¹Long-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).

21C.3 Demographics

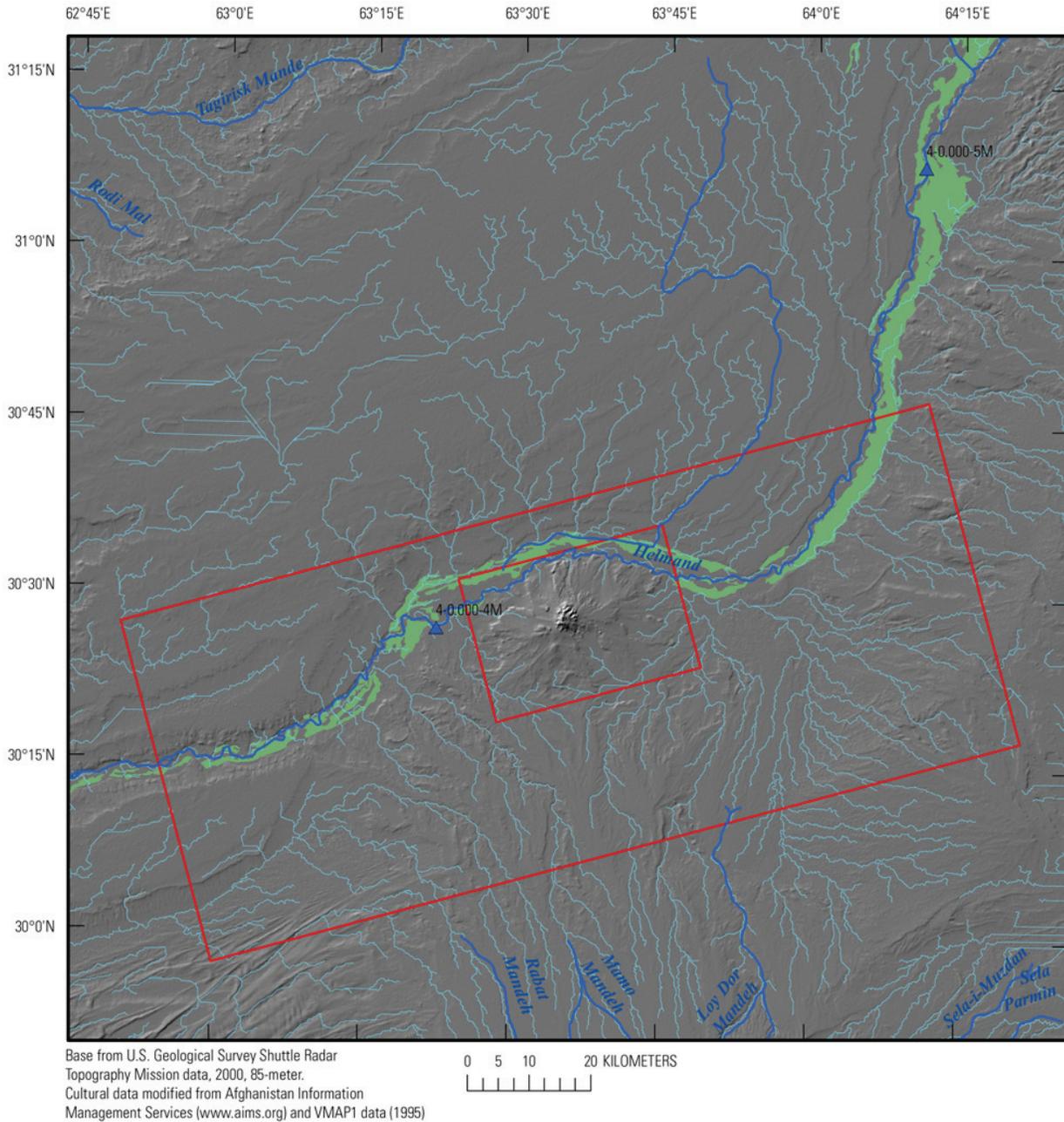
The LandScan database (Oak Ridge National Laboratory, 2010) uses features such as roads or other manmade structures to estimate population density. The population density of the Khanneshin carbonatite AOI as mapped by LandScan indicates a small, dispersed population (fig. 21C–4). The majority of the AOI is uninhabited; where it is inhabited, the population density is in the 26 to 50/km² range. The areas of higher population density in the AOI, several 1-km² pixels with populations of about 500, are concentrated along the Helmand River. The linear patterns of some of the areas where population density is 1 to 5/km² south of the Helmand River might indicate roads or trails and are not indicative of permanent settlements. These areas may also include temporary camps used by nomadic Afghan families or groups. The population density shown in figure 21C–4 has a pixel resolution of about 1 km² (Oak Ridge National Laboratory, 2010).

No dwellings or other signs of permanent settlements were observed in the immediate vicinity of the Khanneshin volcano, in the Khanneshin Volcano subarea, during site visits. Many settlements were observed along the Helmand River (fig. 21C–4) that are supported by irrigation canals that transport water from the river to cultivated areas (fig. 21C–2). Adjacent to the river, shallow groundwater from 3 to 4 m (meters) below ground surface (bgs) is accessed by dug or drilled wells. Hand pumps and electric pumps are used to supply water from wells for domestic use and for irrigation. The settlement of Khanishin village (fig. 21C–1b) is the district center of Reg District and appears to be the closest settlement to the Khanneshin volcano. There are no primary or secondary roads in the AOI and the region is served by tracks mapped along both banks of the Helmand River (Afghanistan Information Management Service, 2003). Some of the mapped tracks lead north into the Dasht-i Margo, but none are mapped south into the AOI in the Registan (fig. 21–1b). Very few settlements are found in the areas outside the Helmand River flood plain in the Dasht-i Margo to the north and the Registan to the east and south.

21C.4 Topography and Geomorphology

The topography of the Khanneshin carbonatite AOI is dominated by the bedrock outcrop of the Khanneshin volcano. The volcano rises to an elevation of 1,291 m above sea level (asl) (Bohannon, 2005) and has an outcrop area of approximately 46 km². The elevation of the base of the volcanic cone at the contact between the bedrock outcrop and the alluvium ranges from 950 m asl on the southwest to 800 m asl on the northeast. The surface of the Registan desert gently slopes away from the volcanic cone (figs. 21C–1a, 21C–2) (Davis, 2006). The gradient to the north, from the bedrock-alluvium contact at the base of the Khanneshin volcano to the Helmand River, is -36 m/km (meters per kilometer). This gradient is representative of the gradient in all directions from the cone out to a distance of at least 6 km. The surface of the Registan surrounding the Khanneshin volcano is planar and is broken only by

occasional hills composed of volcanic and sedimentary rock outcrops, ephemeral stream channels, and barchan dunes. The surface features of this area have been shaped by fluvial and eolian processes.



EXPLANATION

- Boundary of area of interest (AOI) or subarea
 - Irrigated areas
 - Stream, generally perennial
 - Drainage network generated from 85-m digital elevation model (DEM) data, (primarily ephemeral, some perennial)
- Stream or spring** (all types may not be present)
- ▲ Historical streamgage and Afghan identification number, approximately located
 - ▲ Ungaged streamflow estimation point and identifier; see appendix for flow statistics.
 - ▲ Spring or watering hole, VMAP1 data (National Imagery and Mapping Agency, 1995)
 - ▲ Spring or watering hole, alkaline, VMAP1 data (National Imagery and Mapping Agency, 1995)

Figure 21C–2. Historical streamgage locations, digitally generated drainage network, and irrigated areas in the Khanneshin carbonatite area of interest in southern Afghanistan.

The upland surfaces of the Khanneshin volcano consist of weathered volcanic outcrop, weathered volcanic detritus, and wind-blown sediments. The Khanneshin volcano is dissected by deeply incised, V-shaped ephemeral stream valleys (fig. 21C-5). The major ephemeral stream valleys, inferred from the Digital Elevation Model- (DEM) generated drainage network (fig. 21C-2), form a dendritic drainage pattern. During the field visits to the AOI, the major drainages with lengths of 1 km or more were observed to be preferentially oriented northwest to southeast and northeast to southwest. The northwest to southeast orientation corresponds to the orientation of carbonatite dikes that have intruded through the volcanic rocks at the Khanneshin volcano (O'Leary and Whitney, 2005). The channel sides of the large ephemeral streams exhibit deposits of colluvium and boulders. The geomorphology of the drainage channels indicates that precipitation and runoff are sufficient to weather and transport fragments of volcanic rock. The desert plain in the AOI is composed of wind-blown sand and outcrops of volcanic and sedimentary rocks (fig. 21C-6). Active barchan dunes are found to the northwest, west, and south of the volcanic cone.



Figure 21C-3. Photograph of vegetation on the Khanneshin volcano in the Khanneshin carbonatite area of interest in southern Afghanistan.

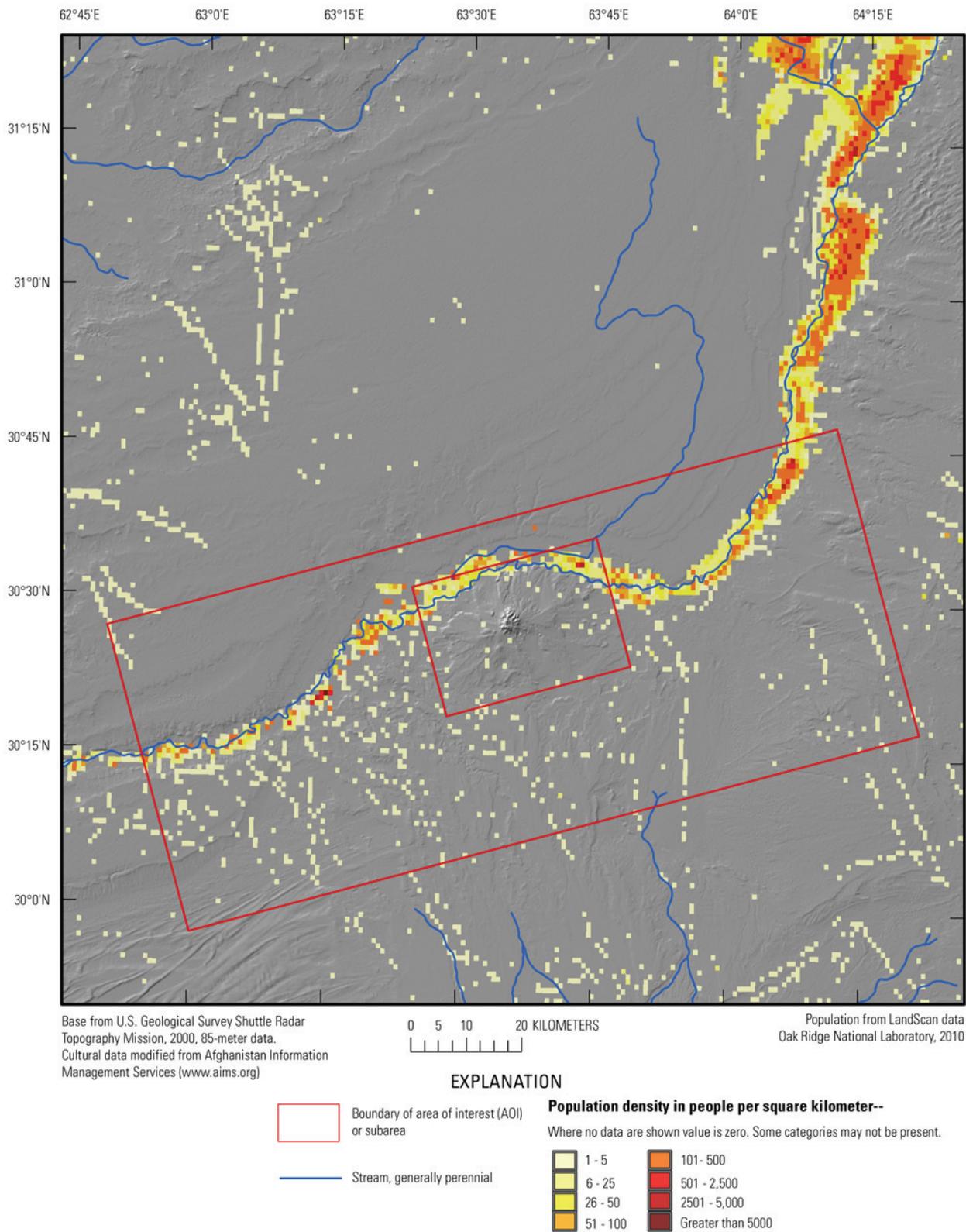


Figure 21C-4. Population density in the Khanneshin carbonatite area of interest and surrounding areas in southern Afghanistan.

21C.5 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 Khanneshin carbonatite AOI is in the Lower Helmand and Registan artesian basins of the Southern Afghanistan Artesian Region. 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 21C–4 with the underlying topography to allow examination of the geohydrology in the context of relief. Figure 21C–7 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 21C–8. 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 “river channel; sands, undifferentiated; conglomerate sediments and rocks; and intrusive rocks and lavas” (figs. 21C–7, 21C–8). 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 cover this AOI is provided by O’Leary and Whitney (2005).



Figure 21C–5. Photograph of topography in the Khanneshin carbonatite area of interest in southern Afghanistan.

The geohydrologic groups within the AOI consist of the intrusive rocks and lavas that compose the bedrock outcrops of the Khanneshin volcano; the conglomerate sediments and rocks; the sands, undifferentiated; and the river-channel deposits. The conglomerate sediments and rocks geohydrologic group has the largest outcrop area. Much of these deposits, especially on the flanks of and surrounding

the Khanneshin volcano, is derived from the weathering of the intrusive rocks and lavas outcrop (fig. 21C–7). Drenth (2009) has estimated the unconsolidated sediments to be thousands of meters thick over basement rocks in some basin settings of the AOI, on the basis of an interpretation of recent and historical aeromagnetic data. A geological sketch map and cross section in Abdullah and Chmyriov (1977, p. 272, fig. 4) depicts conglomerate surrounding the volcanic rocks. The conglomerate is overlain by unconsolidated deposits on the southwest side of the Khanneshin volcano and thick, bedded, caldera-type volcanic rocks on the northeast side. The unconsolidated sediments probably drain quickly and the presence of any shallow groundwater in the AOI is unlikely, except for possible transient zones of saturation that are created following precipitation and runoff events.



Figure 21C–6. Photograph of eolian sand, sparse vegetation, and volcanic outcrops on northwest side of the Khanneshin volcano in the Khanneshin carbonatite area of interest in southern Afghanistan.

21C.6 Surface Water

A network of major, perennial and ephemeral streams in the Khanneshin carbonatite AOI, modified from AIMS (Afghanistan Information Management Services, 1997) and VMAP1 (National Imagery and Mapping Agency, 1995), is shown in figure 21C–2. A network representing likely ephemeral streams, generated with a DEM, also is shown in figure 21C–2. Names of major streams and identification numbers for any streamgages in the AOI also are shown in figure 21C–1*b*.

The Helmand River is the only perennial surface-water body in the AOI and is likely the most readily available water resource. The Helmand River Basin is the largest in Afghanistan. The rivers in the Helmand Basin are fed by melting snow from the high mountains and precipitation from infrequent

storms. Great fluctuations in streamflow, from flood to drought, can be expected (Williams-Sether, 2008). The amount of snowfall and the timing of the snow melt have large impacts on the streamflow in the Helmand River.

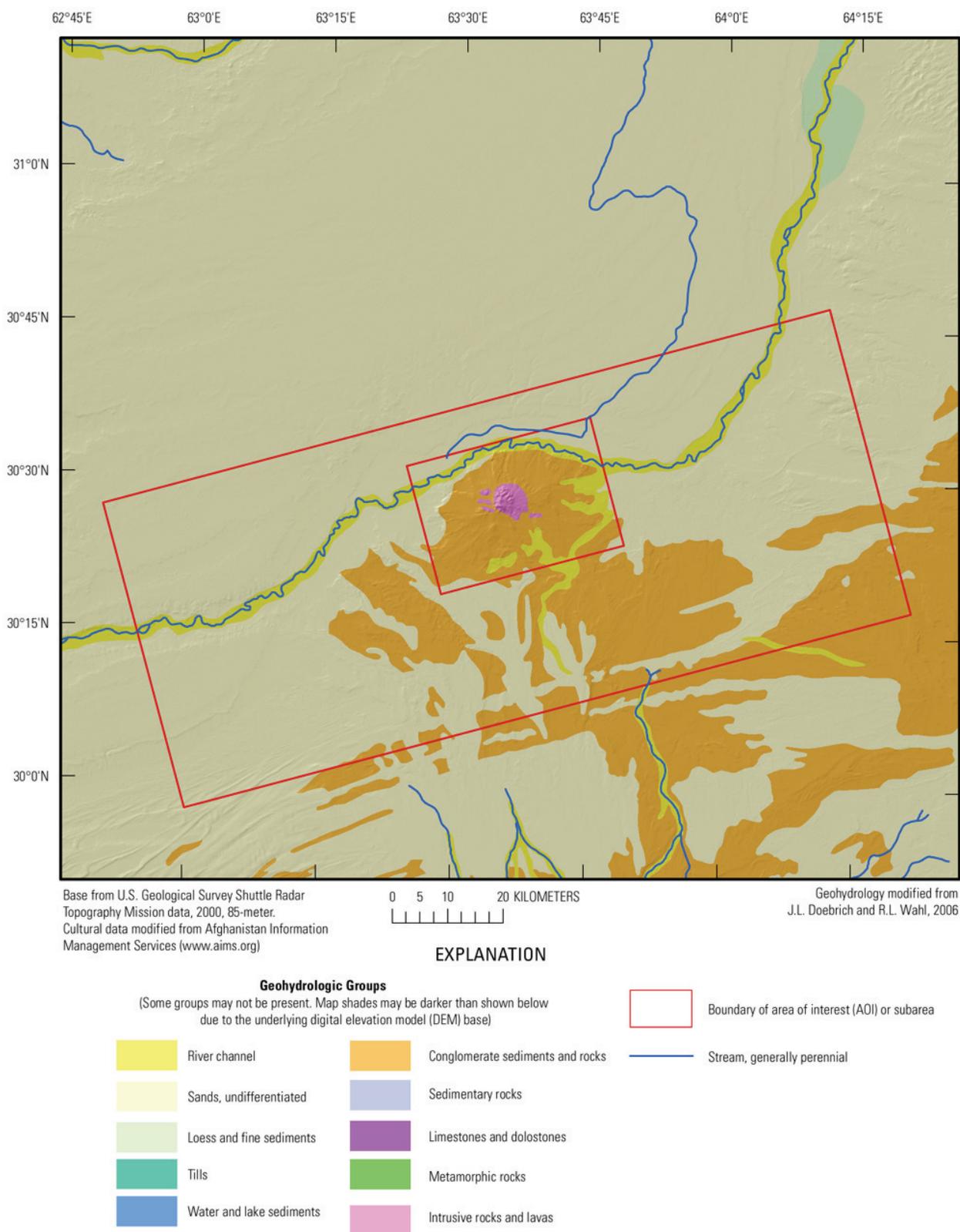


Figure 21C-7. Topography and generalized geohydrology in the Khanneshin carbonatite area of interest in southern Afghanistan.

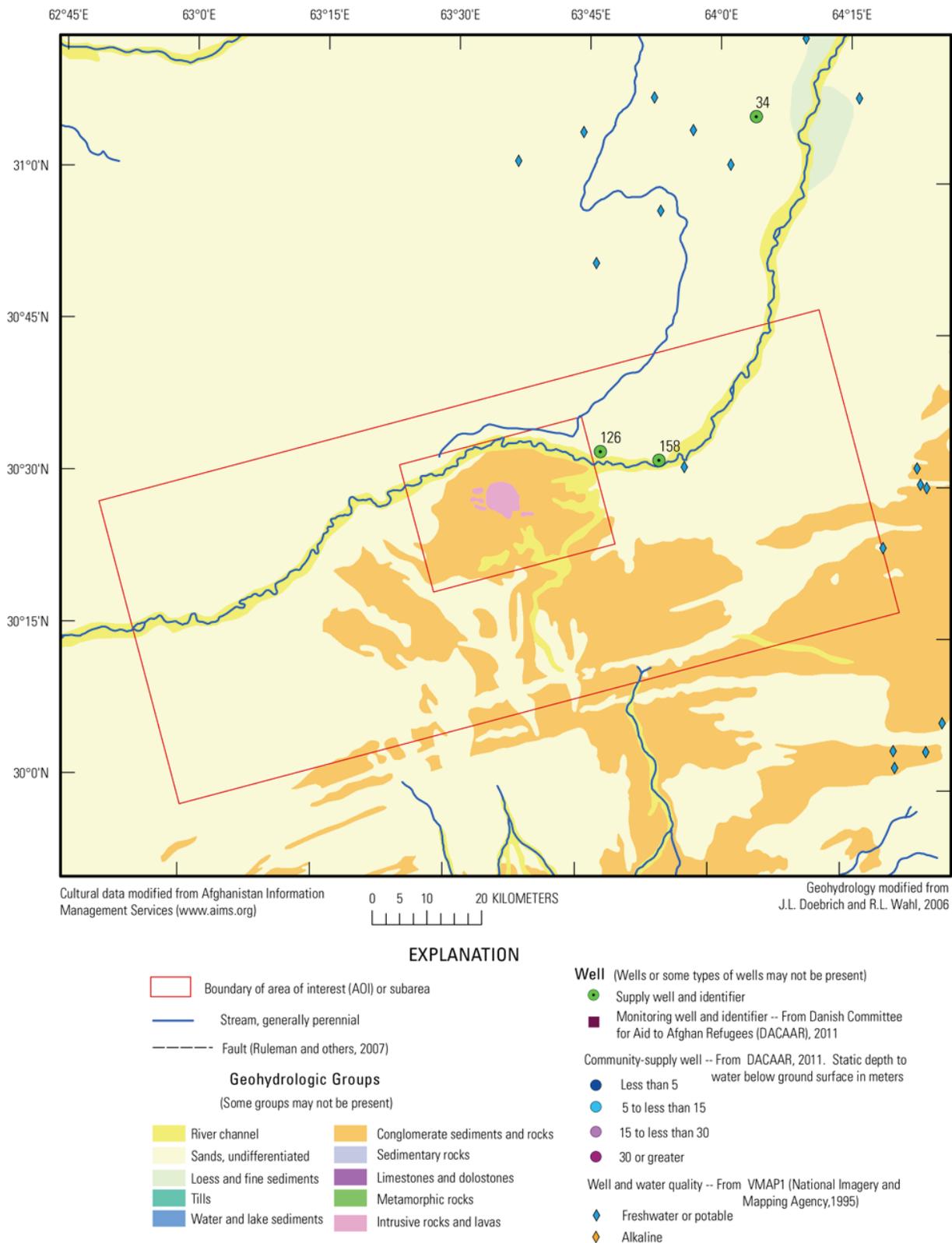


Figure 21C–8. Geohydrology, mapped faults, and well locations in the Khanneshin carbonatite area of interest in southern Afghanistan.

The drainage area at the Helmand River streamgauge station at Malakan (Afghanistan identification number 4-0.000-4M, figs. 21C–1*b*, 21C–2) is 132,880 km², about 17,400 km² of which drains to noncontributing (closed) basins. The Malakan streamgauge station is located about 16 km west

of the base of the Khanneshin volcano (table 21C–2). Streamflow in the Helmand River was gaged by Afghanistan ministries from 1970 to 1978, and mean annual flow for that period was 157 m³/s (cubic meters per second) with a standard deviation of 97 m³/s (Williams-Sether, 2008). The highest maximum monthly mean streamflow was 1,270 m³/s, in April 1976, and the lowest minimum monthly mean streamflow was 13.6 m³/s, in October 1972. The timing and volume of flow in the Helmand River are dependent on reservoir releases and the characteristics of the snowpack in the upper elevations of the headwaters (Favre and Kamal, 2004a). Flows are influenced by water releases from the Kajakai Dam, which is about 250 km upstream from the streamgage station at Malakhan. A streamgage station was re-established at the site of the historical station at Malakan in 2008; however, data from this station were not available at the time of this investigation. Statistical summaries of streamflow data for all available historical gages in Afghanistan can be accessed at <http://afghanistan.cr.usgs.gov/water.php>.

The Helmand River is the only major perennial river in western Asia between the Tigris-Euphrates and Indus Rivers (Whitney, 2006) and, as a result of the sparse precipitation in this part of Afghanistan, is the source of nearly all water resources in the local area. The river supplies water to irrigation canals in nearby villages, and likely recharges shallow groundwater through infiltration into coarse-grained river-channel deposits near the river (fig. 21C–9). The calculated seasonal 7-day low flows with a 2-year recurrence interval varied only slightly, approximately from 51 to 66 m³/s, throughout most of the year (June through February), and increased to 91 m³/s during March through May (Williams-Sether, 2008).

Table 21C–2. Statistical summary of monthly and annual mean streamflows for the Helmand River at Malakan streamgage station.

[m³/s, cubic meters per second]

4- 0.000-4M HELMAND RIVER AT MALAKAN								
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	130	1977	13.6	1972	75.0	45.6	0.61	4.13
November	142	1977	34.3	1972	77.6	38.6	0.50	4.27
December	129	1977	30.8	1972	86.6	30.3	0.35	4.77
January	174	1977	65.4	1971	120	32.4	0.27	6.62
February	226	1970	46.1	1971	147	60.2	0.41	8.08
March	576	1976	24.3	1971	199	165	0.83	11.0
April	1,270	1976	41.6	1971	333	378	1.13	18.4
May	1,200	1976	53.5	1971	394	368	0.93	21.7
June	357	1976	20.7	1971	148	110	0.74	8.16
July	175	1976	15.5	1971	90.9	54.9	0.60	5.01
August	133	1972	16.0	1971	75.0	44.5	0.59	4.14
September	124	1972	14.8	1971	68.5	40.6	0.59	3.78
Annual	364	1976	35.4	1971	157	97.1	0.62	100



Figure 21C–9. Aerial view of the Helmand River on 21 September, 2009, showing cultivated fields and irrigation canals in the Khanneshin carbonatite area of interest in southern Afghanistan.

With the exception of the Helmand River, there is no evidence of perennial surface water in the AOI. No springs were mapped in the AOI in the VMAP1 database (National Imagery and Mapping Agency, 1995) (fig. 21C–2). There is evidence of surface-water flow at the Khanneshin volcano, which is likely the result of short-duration rainfall events. Evidence of these types of flow events was observed on 16 August, 2010, during a field visit to an ephemeral stream on the north side of the Khanneshin volcano. Recent flow in the drainage was indicated by features that typically result from a substantial precipitation and runoff event. Signs of flow included mud cracks on surfaces surrounding plunge pools, pot holes, and low-gradient areas where standing water and sediments accumulated; ripple marks in sediments in these same areas; and bedrock-outcrop surfaces in high-gradient areas (shoots and troughs) with no sediment accumulations, indicating that the surfaces had been washed clean of any sediments. These fluvial features could not have persisted long in the windy environment of the Khanneshin volcano. The flow that produced these features probably occurred within a month of the field visit, and could have been contemporaneous with monsoonal precipitation that can occur in this part of Afghanistan. The vegetation in this wash was actively growing and there were signs of recent animal activity in the drainage.

21C.7 Groundwater

Although few data exist from which to quantify this resource, groundwater is likely present near the Khanneshin volcano and in thick, unconsolidated to semi-consolidated basin-fill sediments

consisting of silt, sand, and gravel in the Khanneshin carbonatite AOI. The basin-fill material may be thousands of meters thick in places (Drenth, 2009). The water level is likely to be near the land surface in the river channel adjacent to the Helmand River and the groundwater is accessed by dug wells. Away from the Helmand River the aquifer is known to be deeper, tens to hundreds of meters deep. Given the characteristics of the region and the age of the VMAP1 database (National Imagery and Mapping Agency, 1995), the wells mapped by VMAP1, shown in figure 21C-8, are likely to be shallow dug wells that access water in a shallow aquifer that is isolated from the deeper aquifer. Deep water-supply wells have been drilled in the AOI and surrounding area by the U.S. government (wells numbered 34, 126, and 158, fig. 21C-8). The wells were drilled to depths of approximately 450 m bgs and the information available indicates that hydraulic characteristics vary considerably between wells. Well 126 is described as encountering all clay, and therefore had no appreciable yield, whereas well 158 had a yield of more than 10 L/s (liters per second). Well 34 is described as artesian, with a potentiometric surface more than 3 m above land surface.

Very few community supply wells were found in well databases at the time of the study (fig. 21C-8). Shallow drilled and dug water wells are probably present in the more densely populated areas along the Helmand River (fig. 21C-4). River-channel sediments in the Kabul Basin were found to have hydraulic conductivities of tens of meters per day (Mack and others, 2010). Where coarse-grained river-channel sediments are present adjacent to the Helmand River (fig. 21C-7), there is the potential for considerable infiltration of river water to a properly constructed supply well. Surface water in areas of high water use may contain agricultural contaminants and other wastes; therefore, the quality of the infiltrated water would need to be assessed. Groundwater withdrawals near rivers would need to be closely monitored to avoid adverse effects on streamflow and on existing surface-water uses.

A hydrologic reconnaissance study was conducted from 20 to 22 September, 2010, near Khanneshin village located along the Helmand River (fig. 21C-1a,b). Well locations were determined and depths to water were measured. The access to well sites was limited to a walled compound at the Khanneshin village about 1.5 km from the active channel of the Helmand River. The compound had been a local government facility, with some small-scale farming, and contained several hand-dug and tube wells. Water levels in the wells were about 4 m bgs (about 633 m asl). Well users indicated that the wells could be pumped for extended periods with no noticeable decrease in discharge. The drilling of a water-supply well with a planned total depth of about 450 m bgs was attempted. Drilling problems resulted in cessation of well drilling at a depth of about 410 m bgs. With the exception of the uppermost shallow aquifer, no water was encountered during drilling.

Groundwater in the AOI probably occurs in shallow zones of saturation resulting from local recharge from the Helmand River. Shallow aquifers may also be found where large ephemeral streams originating on the Khanneshin volcano discharge onto the surrounding desert floor. Perched water could occur here, particularly where porous alluvium overlies less permeable alluvium and bedrock. In “The watershed atlas of Afghanistan, Part IV, Description of watersheds,” Favre and Kamal (2004b) provide the following description: “The water flows from a multitude of seasonal streams back into the Helmand River on each side of the Khanishin Gar volcano.” The reference to seasonal streams supports the concept that ephemeral streams discharging water from the Khanneshin volcano onto the Registan may result in zones of saturation at the discharge areas.

The deeper aquifers, more than 100 m deep and currently (2011) accessed by a few water-supply wells, probably receive recharge from outside the AOI, perhaps even as far as hundreds of kilometers to the north in the Hindu Kush Mountains. Another potential recharge area is to the south in the hills that straddle the Afghanistan and Pakistan border. Groundwater in deep aquifers is likely to be thousands of years old. The quality of water in these deep aquifers is unknown; this water likely has a long residence time and could be saline or contain high concentrations of other ions. Groundwater studies, including chemical and isotopic analysis, would be needed to adequately characterize the groundwater in the deeper aquifers in the AOI.

21C.8 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 Khanneshin carbonatite AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011) were conducted using DEM and natural-color satellite imagery (fig. 21C–10) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite imagery (figs. 21C–11*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 21C–10 were delineated visually, whereas those in figure 21C–11 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 are most productive where boreholes are located in areas of highly fractured bedrock. Areas where lineament density is high (figs. 21C–10, 21C–11*a*, and 21C–11*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 DEM and natural-color satellite imagery lineaments analysis in the AOI was limited to the Khanneshin Volcano subarea based on areas of mapped bedrock. The ASTER lineament analysis included a larger area and limited automated topographic surface analyses (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011). However, an orthogonal network of north-northwest- and east-northeast-trending lineaments is present that indicates a likely pervasive fracture pattern. Where these patterns intersect, there may be areas of potentially increased transmissivity and secondary porosity. Some of the ASTER lineaments coincide with the DEM lineaments and others follow features near the Helmand River that are likely to be related to irrigation networks. The nature of other ASTER patterns is not clear and their interpretation would require comparison with additional data.

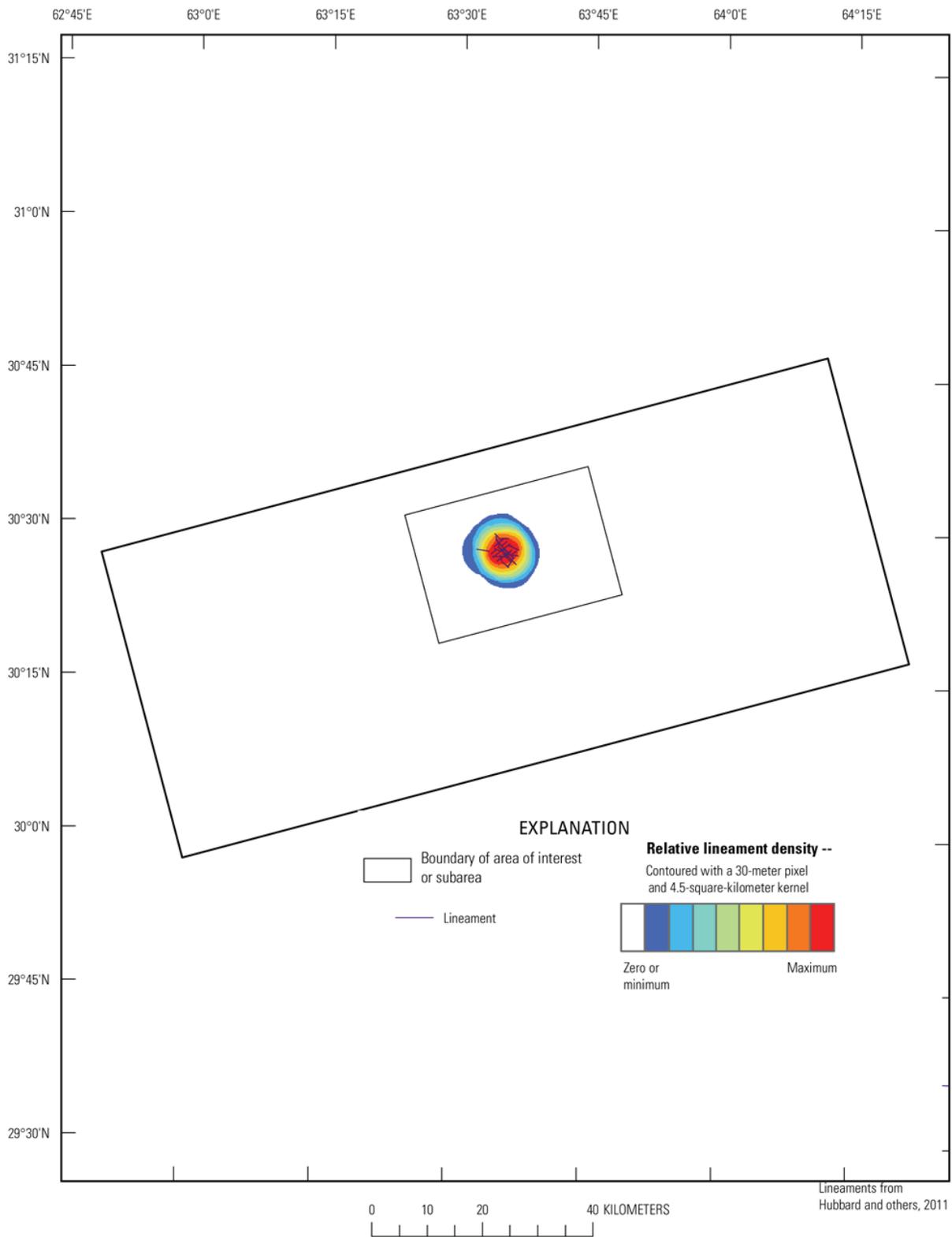
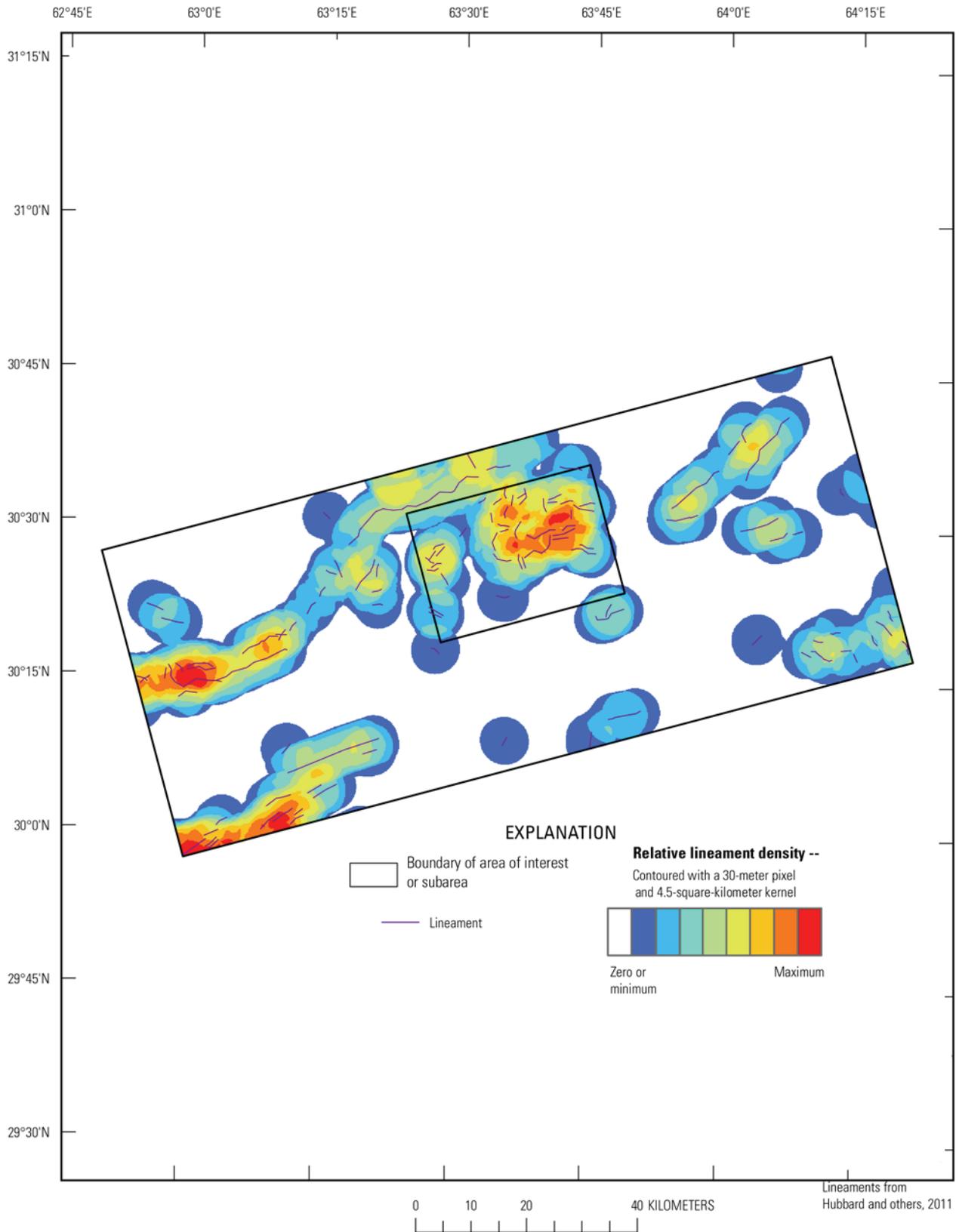


Figure 21C–10. Lineaments and lineament density based on 30-meter digital-elevation-model data and natural-color Landsat imagery in the Khanneshin carbonatite area of interest in southern Afghanistan.

a



b

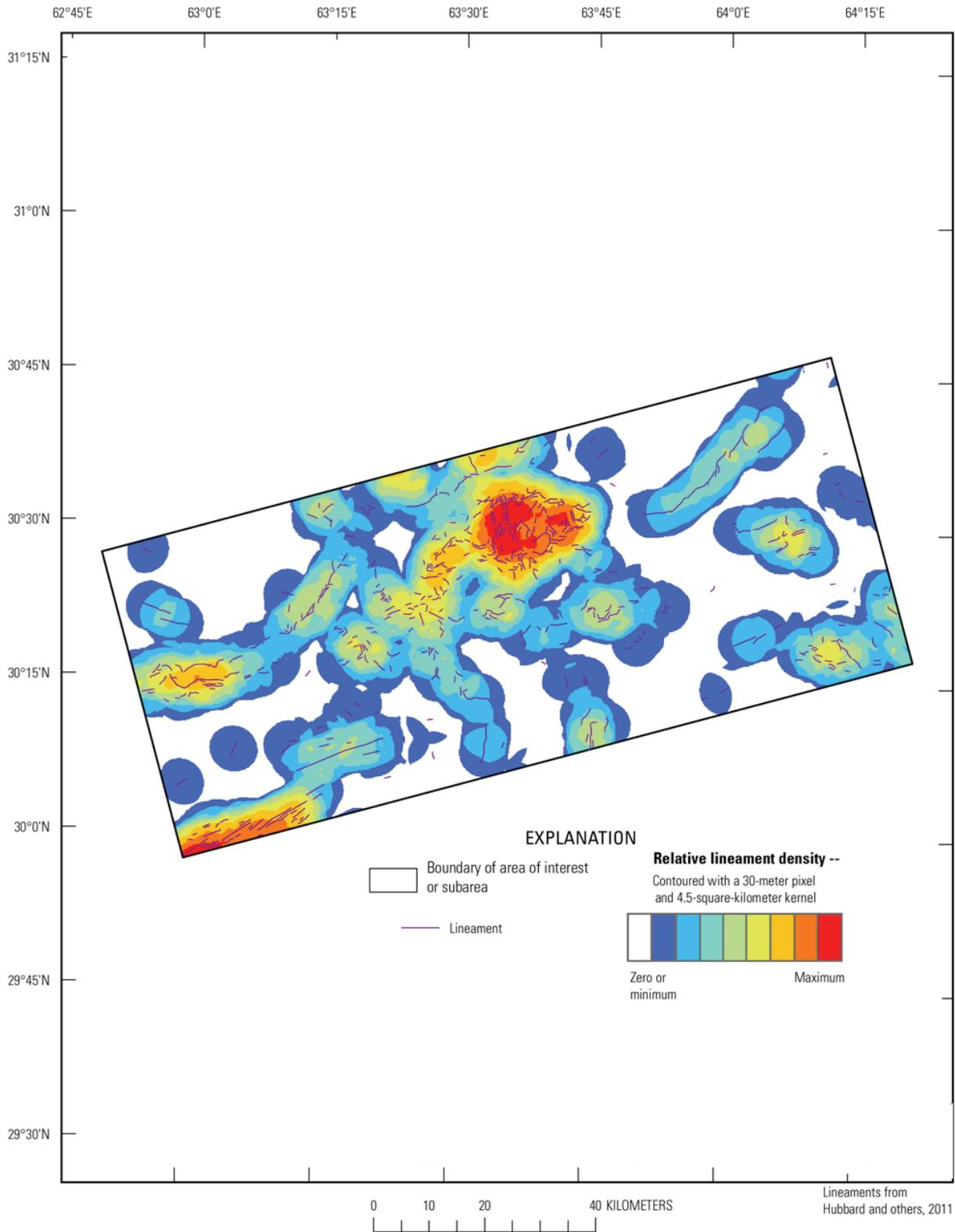


Figure 21C-11. (a) Lineaments and lineament density based on 30-meter multispectral Landsat imagery and (b) lineaments and lineament density based on 15-meter multispectral Landsat imagery in the Khanneshin carbonatite area of interest in southern Afghanistan.

21C.9 Summary and Conclusions

The Helmand River is the most readily available source of water in or near the Khanneshin carbonatite area of interest (AOI). It is used for irrigation and is likely to be the primary source of recharge to shallow alluvial aquifers adjacent to the river. Close monitoring and careful management of large withdrawals from the Helmand River to support mining or other activities in the AOI would help to avoid adverse impacts on local water uses. The flow of water in the Helmand River varies seasonally, with peak flow usually occurring in the spring and early summer and low flow typically occurring from late summer through winter. Renewed streamflow monitoring and determination of the characteristics of flow would be needed to assess whether, when, and how much water could be diverted for use. The total amount of water available in the Helmand River system depends on snowfall in the Hindu Kush Mountains. The amount of measured and estimated snow in the mountains can be used to predict whether the runoff and streamflow will be above average, normal, or below average.

Ephemeral runoff from the Khanneshin volcano most likely recharges local shallow perched aquifers; however, this resource is likely to be limited and may be fully utilized. Recharge to deeper aquifers in and near the AOI probably is derived from distant rather than local sources. Deep groundwater resources are also likely to be thousands of years old. A program of chemical and isotopic analysis would help to assess the characteristics and sustainability of this resource. The production of water from deeper aquifers may support new uses; however, overuse of the water resources in a desert environment can easily result in adverse effects. The quality of water in deep aquifers is unknown at this time. It is possible that water in deeper aquifers has a long residence time and is saline or contains high concentrations of other ions. Field investigations including geophysical surveys, borehole hydraulic testing, and analysis of water quality would be needed to adequately characterize the availability and quality of groundwater in the AOI.

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