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Hazardous Terrain: The Need for High Mountain Cartography and Remote Sensing in the Pamir Mountains, Tajikistan

Abstract

The Pamir Mountains form the complex orographic node where the Hindu Kush, Karakoram, Tien Shan, Alayskiy and Kunlun Shan ranges converge. They have a long history of catastrophic natural disasters. These mountains are a new frontier for modern high mountain remote sensing cartography, particularly as it applies to natural hazard monitoring and mitigation. The region is undergoing rapid return migration after nearly 50 years of Soviet resettlement to the lowlands. The addition of refugees, international immigration and landless types searching for available land add to and complicate the resettlement pattern.

Many new mountain residents are at risk from earthquakes, macro and micro mass wasting, glacial and fall lake outbursts, floods, snow avalanches and high winds. Large and often seismic-induced earthflows have created several lakes that inundate Southeastern canyons. Geomorphic evidence here and in Western Foothill sites indicates historic and continued formation.

Contemporary scientific analyses of hazard zone land use, prediction, mitigation strategies and maps are lacking in this politically sensitive multifrontier. The development and application of modern cartographic, remote sensing, and GIS techniques could aid government and NGO donor agency attempts to evaluate, monitor and mitigate these hazards. Recent declassification of historic imagery, coupled with powerful new hardware and software capabilities, invites further investigation. Unfortunately, the recent civil war, economic uncertainty and the regional demographic caldron complicate field research and cooperative efforts.

1 Introduction

The Pamir Mountains rise above the Central Asia steppe and desert where the Hindu Kush, Karakoram, Tien Shan, Alayskiy and Kunlun Shan ranges converge. They have a long history of catastrophic earthquakes, landslides, wind storms, snow avalanches and epic floods. In particular, large and often seismic-induced earthflows have created elongated lakes in several drainages.

The Pamir are also in a period of rapid return migration following nearly fifty years of involuntary population removal under Soviet authority. The use of high mountain remote sensing cartography could assist these “new” settlers in disaster planning and mitigation, but there is little of either in this financially strapped and politically troubled republic. This paper explains the situation. The problem is outlined in political and demographic context. The salient biophysical traits are then identified with their corresponding natural hazards. The conclusion recommends research needs for hazard mitigation.

Field Research in Tajikistan

Fieldwork for this study began within Tajikistan in 1991. Travel restrictions, underdeveloped infrastructure, natural hazards, government malaise, hyperinflation, and severe civil unrest, all complicated scholarly pursuit in Tajikistan. Under the auspices of the Soviet and Tajik Academy of Sciences, the author visited every region mentioned below. Field techniques included: interviews (for political and regional analyses); rapid rural appraisal (to ascertain crop patterns and return migration); interpretation of aerial photographs, satellite imagery (various scales), Soviet 1:125000 scale topographic maps, large scale imagery (to analyze vegetation, glaciation, and hydrologic elements); and extensive field reconnaissance (to determine scientific veracity of the above sources). The author field checked approximately 90 percent of the Pamir Mountains, including a portion of each *rayon*, by foot, mule, truck, light aircraft, or helicopter. Additional work in the adjacent Chinese Pamir (Xinjiang), Kyrgyzstan and Moscow completes the field analysis.

Location and Subregions

The modern state of Tajikistan is 143,100 km^2, of which 93 percent is mountainous, with elevations from 300 m to 7495 m. The east-west axis stretches for 700 km; the north-south distance is 300 km. Almost half the 3000 km frontier is shared with China (430 km) and Afghanistan (1030 km). The narrow (15 to 65 km wide) Afghan Wakhan Corridor separates Southeastern Tajikistan from Pakistan.

The Pamir-Alai comprises eastern Tajikistan where the southern Hindu Kush merges with the Karakoram-Himalaya. The Tien Shan lie south of the main Pamir Crest. These independent ranges radiate separately from the central and rectangular shaped mountainous "Pamir Knot." The axis is centered upon 38°30'N; 73°E. Over 90 percent of the land is within the Gorno-Badakshan Autonomous Oblast of Tajikistan (Figure 1).

Complex topography divides the Pamir into distinct subregions. Four independent spurs comprise the Western Foothills—the Peter the Great, Darvaz, Vanch, and Yazgulem ranges—which align latitudinally from the plains of western Tajikistan to the High Pamir. These abruptly intersect the High Pamir Academy of Sciences Range *(Academia Nauk*) near the 72°E meridian. The Academia stretches north-south for 180 km and includes many summits above 6000 m elevation. The more arid Trans-Alai radiates eastward from the northern extent of the Academy Range. East of the Pamir crest the more arid Southeastern Pamir and the Pianj River Corridor form numerous deep canyons where the majority of landslide-dammed lakes occur. From here the mountains give way to the Pamir Plateau, a 4000 m undulating and windswept plain similar to the Chang Tang in adjacent Tibet.

2 The Problem: Political Change, Return Migration, and Mountain Hazards

Soviet controls kept the Pamir off-limits to almost everyone during most of the 20th Century. Furthermore, Stalin's resettlement program largely depopulated the region from 1940 until return migration began in the late 1980s. From the perspective of hazard and risk management, 70 years of Soviet control: 1) forced depopulation of the Western Foothills; 2) depopulated the Eastern Pamir or relocated people into collectivized farms; 3) collectivized subsistence farms at the base of the Pamir, some of which still operate today, accelerating soil erosion and mass wasting; 4) developed water resources to complement new large scale agricultural and hydropower schemes, much of which have been subsequently destroyed by floods; 5) enforced severe travel restrictions across the Afghan and Chinese frontiers; and 6) severely curtailed domestic research and international scientific inquiry into the Pamir.

Gorbachav's *Peristroika* initiated resettlement into the Pamir. The Soviet devolution and Tajik independence in 1991 then accelerated two distinct population shifts throughout the Pamir that have put thousands of mountain residents at risk.

The first shift involves the Western Foothill return migration. Depopulation began here in the 1940s when Stalin ordered Tajiks south of the densely settled Vaksh-Surjov corridor to relocate in the southwestern floodplains near Dushanbe. Their arrival was synchronous with irrigation development designed to produce gun cotton for World War II armaments. A history of destructive earthflows that annihilated or damaged kishlaks was also used to justify relocation. In 1995 the present Tajik government estimated that 12,000 people have return migrated to the Western Foothills but the actual figure is now augmented by refugees from the Tajik Civil War, immigrants from adjacent ex-Soviet states and Afghanistan, and other Tajik lowlanders who are attracted by "new" land.

The second shift occurs in the Gorno-Badakshan Autonomous Oblast (GBAO) where Stalin forced Pamirians into farming communes during the 1950s. Most of these were located along the Pianj River or at the base of the eastern Pamir. Post colonial migrants within GBAO are leaving collective farms for either rural or urban locales, or they move illegally between northern Afghanistan and the Tajik Autonomous County in Xinjiang, China. The State Republic Committee for Statistics (SRCS 1992) expects a 20 percent population increase in ethnic Pamirian villages by 2005, although high infant mortality, severe food shortages and disease outbreaks (especially typhoid and dysentery) are curbing this growth.

Obratnichestvo (outmigrat ion of Russians from Tajikistan) is not significant here as most Russians lived in the Tajik capitol of Dushanbe. This, along with Tajik independence and the post-colonial economic slump underlies Moscow's reluctance to fund hazard studies in the Pamir.

3 Biophysical Traits and Principle Hazards

Geologic Underpinnings and Seismicity

The Pamir result from the largely basaltic angular Indian Ocean plate collision with the less dense Mesozoic Tethys sea strata of Eurasia (Sonnenfeld 1981). The weaker sediments comprising Central Asia and the present day Pamir landscape folded and faulted as the Indian plate moved northward and subducted under Eurasia. The current vertical displacement is 1 to 2 cm per year (Desio 1976; Searle 1991).

This high seismic risk is not readily apparent as the low population density during the past 50 years reduced earthquake casualties. Over 500 earthquakes exceeding Richter 5 have rocked the Pamir since 1900 (Badenkov 1992). Three of these temblors proved especially catastrophic: the Karatag (1907), Sarez (1911), and Khait (1949). The earthflow triggered by the Khait quake buried a *kishlak* by the same name and claimed over 24,000 victims. These temblors and countless lesser ones trigger the episodic mass wasting of the uplifted and deformed Tethys Sea deposits.

Recent advances in technology facilitate monitoring seismic events via the internet, and predicting potential areas of concern using newly developed hazards software (FEMA 1997).

Geomorphic Hazards – Mass Wasting, “Fall Lakes” and Outburst Floods

Six factors account for the ubiquitous slumps, landslides and earthflows in the Pamir: 1) steep terrain where numerous slopes exceed 30°; 2) weathered and unconsolidated Tethys Sea strata that comprises much of the Pamir surface lithography; 3) intense seismicity; 4) an arid climate that supports sparse vegetation to anchor sediment and absorb runoff; 5) episodic torrential rainfall, usually in spring, punctuating the otherwise dry climate; and 6) anthropogenic livestock grazing, forest clearing, water diversions and agriculture which reduce soil moisture storage capacity.

Pushkarenko and Nikitin (1988) identify 3000 large and small lakes in the former Soviet Central Asian cordillera. These result from either tectonic, glaciogenic, hydrogenic (karstic, erosion seepage and thermokarstic), or fall processes. Fall lakes resulting from mass wasting of rockfalls, landslides, avalanches and deposition, lie in the 1500-4000 m range. They found over 50 fall lakes with dam volumes ranging from 0.1 m^3 to 2.2 billion m^3 of rock and soil material. “The vast majority of such lakes are associated with tectonic fault elements, with falls of enormous volume occurring next to smaller ones” (Pushkarenko and Nikitin 1988, p. 11). Lake Sarez located in the Zulumrat-Kyzyldang Deep Fault fits their model and is the largest of these fall lakes. During the 1990s this author also noted evidence of previous complete or temporary blockage in deep fault zones of the Obi Mazar River, Obi Hingou River and 12 other drainages.

Failed landslide dams have a devastating history. On a global scale, Hewitt (1997) identifies 13 instances where large natural earthflows created sediment dams that later failed and caused additional major damage. In all cases, the failure occurred with little forewarning and resulted in massive downstream damage. The lithographic history, reservoir size, and downstream settlement characteristics make Sarez Lake and several smaller bodies a potentially enormous tragedy waiting to happen. Seismic action can also trigger glacial lake outburst floods (*Jokulhlaup*). Over 8,500 glaciers blanket six percent of the Pamir surface area and store 556 km^3 of water. Melting ice feeds 947 rivers totaling 28,500 km in length, and with precipitation, yields 61.8 km^3 of annual runoff (Narzekylov and Staniukovich 1968). Suslov (1961) estimates the Fedchenko system, with 198,900,000 m^3 of ice in a 75 km long trough, is the largest glacial system in Central Asia. The glacier averages five km wide and 500 m in thickness; six of 37 tributary glaciers exceed 10 km in length (e.g., Nalivkin Glacier, Vitkovski Glacier, and Academy Nauk Glacier). There are also large ice and firn fields in the Trans-Alai, northeast of the Academy Range where the Saukdara Glacier below Peak Lenin (7134 m), the Yakuima Glacier below Peak Korundy (6549 m), and Krasina Glacier below Dzerzhinskovo Peak (6717 m) compare to the large Pamir glaciers.

The outlet glaciers here are unusually large relative to their supporting firn fields. The Russians classify Central Asian glaciers as a Turkestan type. The shaded canyons protect glacial ice from melting and provide the incline for snow accumulations that repeatedly avalanche onto the main trunk. Severe physical weathering (summer diurnal temperature range can equal 33°C) promotes frequent rockfall up to 100 m in thickness that insulates ice. The debris often blankets the entire ablation zone, reducing melt. Reworked moraine debris (often 200 m high), numerous erratics and isolated ice cores, braided channels and moraine lakes characterize glacial termini. The lakes are a source of sudden and often catastrophic flooding when moraine and ice dams fail in response to seismic tremors, ablation or surging, a phenomena also identified in the Karakoram (Hewitt 1964, 1982) and Khumbu Himalaya (Ives 1986; Watnabe, et. al. 1992).

Within Central Asia there is a long history of debris and earth flows resulting from failed debris dams. Mallitskyi (1929) identifies eight over the period from 1880 to 1930. Large mudflows traveled down the Sukhandrya (1896), the Sarydzhas (1902), the Zarafshan River (several documented since 1900), Lake Issyk (1963), and Lake Yashinkul’ (1966) {Table 1}. The government has also destroyed several other small debris dams to mitigate uncontrolled flooding (Pushkarenko 1982; Badenkov 1992).

The 1966 breech of Yashinkul’ deserves special mention as it provides the most recent analog to a potential partial or complete breech or dam failure of Lake Sarez. Two large earthflows and several minor slides between 1833–1836 dammed the Tegermach River in the Kichik-Alai range. Seismic action triggered most but not all of the obstructive material that eventually produced a dam 120-170 m high. An estimated 20 million m^3 of blocks, rubble and fine sediment bury a terminal glacial moraine.

For 133 years water backed up behind the dam until the 1966 Tashkent earthquake jarred the consolidated foundation. Severe aftershocks the next month increased seepage through the dam until a partial breach produced two enormous waves equaling 5,000 m^3/s of water and stone mudflow.

Sarez Lake in the Southeastern Pamir is currently the largest natural sediment reservoir in Central Asia. Situated east of the Pamir crest in Badakshan, the lake formed when a 1911 tremor shook loose six billion metric tons of debris, damning the Murgab River. The water level rose 240 m in three years and inundated 75 km before filtration through a subterranean outlet reestablished the river. The lake level currently rises up to 20 cm annually. Failure of the Sarez dam is a potential cataclysmic disaster that would alter the economy and socio-political environment of Tajikistan. The resulting flood would quickly reach the Amu Darya system, and then affect 3 million downstream inhabitants from Badakshan to the Aral Sea. The size and complexity of this problem will also almost certainly require financial and technical assistance from the international community. At stake are many lives, national pride, future economic development and significant fresh water resources.

A perusal of the internet suggests that multitemporal imagery of the Yashinkul' and Lake Issyk lake breakthroughs of the 1960s may provide ample material for testing predictive capabilities of modeling routines in order to develop meaningful disaster/mitigation plans for Sarez lake, and the Pamir bioregion. This would also require digitizing large scale topographic maps to create Digital Elevation Model files for terrain analysis prior to, during dam formation, and subsequent to past breakthroughs.

Table 1. Lake Breakthroughs in Central Asia

Yashinkul', Southeastern Pamir	1966	Breakthrough of fall dam triggers disastrous mudflow
Zarafshan Valley, Northern Tajikistan	1964	Aini rockfall created lake that was artificially voided to avoid flooding
Lake Issyk, Eastern Kyrgyzstan	1963	Breakthrough of fall dam triggers disastrous mudflow
Fandarya, Western Tajikistan	1926	Fall lake of smaller volume formed above village of Zaisun; lake emptied gradually
Sarydzhas, Pamir-Alai	1902	Fall lake breakthrough caused a mudflow which swept away several villages
Zarafshan River, Northern Tajikistan	1900s	Many rockfalls in narrow valley cause temporary damming and large floods
Sarydzhas River, Pamir-Alai	1898	Mountain lake breakthrough triggered a mudflow
Fandarya River, Pamir-Alai	1880	Artificial lake of 20 million cubic m was voided

Source: Pushkarenko & Nikitin (1988), Badenkov (1992)

Climate Related Hazards

The principle climate hazards are high winds and flooding. Tajikistan is 5500 km distant from marine influences which produces a continental climate characterized by long, hot summers and short, cold winters. The great diurnal and seasonal temperature amplitude results from atmospheric circulation, continental location, and the division of Central Asia into a terrain of mountains and deserts.

Winds

High winds damage human structures and crops almost every year. Afghanets are strong arid and typically westerly winds that produce huge dust storms of up to five days duration. Particulate matter lifts 3500 m high and can take 10 days to settle (Dushanbe Climate Station 1992). The process culminates during July and August when the wind combines with the hot desert atmosphere to produce unusual turbulence and extreme dust conditions. Afghanets severely impede all travel.

Very hot and arid desert harmsils (hot stream) also bring strong winds (6 m/s), prolific dust, an increase in temperature (up to 47°C maximum), and low relative humidity [8 percent (Lyndolph 1977)]. These east or southeasterly winds are characteristically associated with the warm sector of a cyclonic storm. High velocities occur in summer when air constricts while passing over mountains. Severe storms deplete fruit trees of both leaves and fruit, and dislodge roofs from barns and homes.

High wind frequency increases with elevation. Dushanbe at the base of the Western Foothills records between 6 and 12 days of dust annually (Dushanbe Climate Station 1992). Balshova et al. (1960) report ceaseless katabatic winds and frequent dust storms (15 to 20 days per year; a maximum of 40 days has been recorded) in the upper Pamir-Altai. Winds associated with frontal systems intensify with elevation as the systems approach the Pamir Foothills and air flow narrows between the fronts and the mountain slopes. Pervasive Fohn and Katabatic winds are common but lesser threats to human settlement. Mapping these high risk zones will support related scientific inquiry.

Storms

Winter and spring cyclonic storms of Mediterranean Sea or Gulf of Arabia origin account for over 90 percent of precipitation. The juxtaposition of east-west oriented foothill ranges with the north-south oriented Academy Range traps moisture from both sources. March is normally the wettest month when flooding poses the greatest threat. Precipitation generally increases with altitude, but complex terrain creates many arid rainshadow pockets such as the Pamir Plateau and the Pianj River Canyon.

Snowmelt and glacial runoff from the High Pamir sustain Central Asia’s two most important rivers. The larger Amu Darya drains the Pamir via the Pianj and the Surjov, which join near Korghan Tube. This 2500 km long river separates Tajikistan from Afghanistan and flows through Turkmenistan to the Aral Sea. The Syr Darya drains northward from the Trans-Alai through Kyrgyzstan and Uzbekistan for 2200 km to the Aral Sea. In these drainages runoff peaks once after the spring rains and again in late summer following maximum glacial melt. Annual flooding and steep terrain limit settlement to alluvial bottoms, terraces and some interfluvial sites, although the increasing population surge discussed above forces migrants to more marginal sites well within the range of periodic flooding.

Just prior to collapse, Moscow planned 21 hydroelectric stations on the Vaksh and Pianj Rivers. The flagship site was the massive Ragoon Dam in the Vaksh Valley. Progress was intermittent until spring rains in 1994 destroyed the partially completed dam. Despite outside loans (USDOE 1997; IMF 1992) the severe damage is likely irreparable. This thwarts Tajikistan's best opportunity for both regional flood control and exporting hydropower to adjacent states. A systematic study applying current digital mapping science methods could help determine the future of Central Asia's most critical resource.

4 Research Needs and the Role of Remote Sensing Cartography

The Pamir offer dramatic mountain scenery with many unclimbed peaks, deep valleys with untilled fluvial terraces, and spectacular whitewater streams that have never seen a canoe or kayak. But there are also extraordinary seismic and geomorphic hazards lacking the data to predict and mitigate damage. Tajik independence opened the region to the outside world for the first time since the early 20^{th} Century. This provides opportunity to analyze—with modern cartographic, remote sensing, and GIS technology—the temporal and spatial characteristics of the hazards described above.

The author suggests a scientific approach for the Pamir Bioregion based to some degree on the model applied to the Sierra Nevada Ecosystem of the United States (SNEP 1996). In order to investigate the feasibility of such an endeavor, a preliminary plan to build a fully functional geographic information system (GIS) for the Pamir Bioregion follows:

1. Catalogue available imagery ranking each for potential monitoring/modeling use.
2. Catalogue available Digital Elevation Model (DEM) files and sources necessary to digitize these files.
3. Catalogue available hazards information for the region from historical documents, studies, and current digital monitoring systems.
4. Construct a detailed GIS/modeling proposal to identify specific needs and goals.
5. Generate a prioritized list of imagery and DEM files to be obtained and digitized. (Data from recent space shuttle imaging systems may be of use here for current base data.)
6. Seek funding.

In addition to specific hazard applications mentioned above, applying cutting-edge mapping science techniques to the Pamir region would greatly assist the emerging political structure and the international community to manage this remote region in such areas as:

1. Water content, global warming issues and water export possibilities.
2. Vegetation change, conservation and habitat analysis (perhaps following the model provided by the GAP Analysis Project in the United States).
3. Infrastructure and hydropower potential analysis.
4. Settlement possibilities-hazards and agricultural potential.

The opportunity for cooperative investigation with knowledgeable Russian and Central Asian colleagues is excellent. Updating the present Soviet Topographic Series (various scales), and continuing coverage via aerial photography and routine satellite imagery are a high priority. Constructing ICIMOD-type (Ives and Messerli 1981) Hazard Maps is paramount. Updating and developing these research tools utilizing digital systems like *Hazus* (FEMA 1997) would dramatically improve the opportunities for hazard planning and mitigation.

Field Research Remains Problematic

Unfortunately, there was only a brief window between the end of Soviet rule and the onset of civil war in Tajikistan. Civil unrest wracked this tiny republic just prior to the Soviet dissolution (Malick 1992; Bee 1993).The failure of the new Tajik government to quell uprisings and forge a national identity was fodder for rebellion (Mirsky 1992; Emadi 1994). Sporadic post independence uprisings gave way to civil war in August 1992. Since that time gunfire and exploding mortar shells, road blocks, severed rail and airport links, mass emigration of Russians to Siberia and the Moscow Oblast, ethnic cleansing of neighborhoods and former work brigades, and open hostility demarcate post-independent Tajikistan (La Vine 1992; Sharif 1993). The combination devastated government agencies, industry and the service sector. Conventional civil war began in 1993 and in varying severity continues to the present. Looters and raiding parties, some from Afghanistan, complicate the violence. The gross violations of human rights documented by Amnesty International (1993a, 1993b) and Helsinki Watch (1991) include summary executions, disappearances, and discrimination on the basis of ethnic and regional origin. Casualties include 50,000 dead and 500,000 refugees, of which a third fled to Afghanistan and adjacent Central Asian states (Hafizullah 1994). The carnage destroyed 30,000 homes and leaves no part of the industrial or agricultural infrastructure undamaged. All told about 25 percent of the population were killed, maimed, forced from their homes or lost livelihoods as a result of the conflict.

The upheaval increases human migration into the Pamir. Refugees seek shelter from the violence while others abandon the dangerous urban locales to reunite with previously relocated families. In addition the civil war exacerbates government travel restrictions, an undeveloped infrastructure, government malaise and hyperinflation, all of which complicate meaningful scholarly pursuit in the Pamir Mountains (Cunha 1994).

5 Conclusion

The Pamir represent a new frontier for modern high mountain remote sensing cartography, particularly as it applies to natural hazard monitoring and mitigation. The region is undergoing rapid return migration after nearly 50 years of Soviet resettlement to the lowlands. The addition of refugees, international immigration, and landless types searching for available land add to and complicate the resettlement pattern. Many new mountain residents are at risk from earthquakes, macro and micro earth mass wasting events, outbursts from glacial and fall lakes, floods, snow avalanches, and high winds.

Contemporary scientific analyses of hazard zone land use, prediction, mitigation strategies and maps are lacking in this politically sensitive multifrontier. The development and application of modern cartographic, remote sensing, and GIS techniques could aid government and NGO donor agency attempts to evaluate, monitor and mitigate these hazards. Unfortunately, the recent civil war, economic uncertainty and the regional demographic caldron complicate field research and cooperative efforts.

6 Acknowledgements

The author thanks the United Nations University (Tokyo), the Russian Academy of Sciences (Moscow), the Tajik Academy of Sciences (Dushanbe), and the United States Agency for International Development (Washington, D. C.), Dr. Yuri P. Badenkov (Russian Academy of Sciences), and Dr. Anvar Buzurukov (*Goskomproda*, Dushanbe) for supporting this study. Dr. M. F. Buchroithner (Institute for Cartography, Dresden University of Technology, Germany) provided significant editorial critique.

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