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Exploring indirect evidences of environmental change in the Pamir-Alai Mountains (Central Asia) during the last century

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by:

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The thesis explores several types of environmental change in the Pamir-Alai mountainous region (Central Asia) through the indirect observations. The paper assesses three geographic areas: the Kuhistoni Matcha, the Fan Mountains and the Lenin Peak, which have been selected among the most popular touristic sites with sufficient availability of and access to the written records of indirect observations. The research focuses on glacier melting and lakes' water level fluctuations. The results of the research confirm that indirect evidence of environmental change in the Pamir-Alai mountains as reported by observers is well consistent with the results and trends based on the systematic instrumental observations and purposeful data collection.

Keywords: indirect observations, glacier melting, climate change, Pamir-Alai

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LIST OF ABBREVIATIONS

GLOF	Glacial Lakes Outburst Flood
CEU	Central European University
IPCC	Intergovernmental Panel On Climate Change
km	Kilometre
m	Metre
m.asl	Metres above sea level (altitude)
pers. com	Personal communication
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

1. INTRODUCTION

1.1. Setting the scene

In the past century and increasingly in the 21th century the issue of global environmental change, in particular climate change, attracts major attention of scientists, policy makers and the general public, standing as one the most urgent issues on the modern global and national development agenda. The evidence of environmental change is exceptionally dramatic in the glacial and mountain systems, the Arctic and other climate sensitive areas and is reported globally by the scientific community, professionals in certain occupations and indigenous people. The need in a comprehensive study and analysis of environmental transformations encouraged the scientific community to establish, maintain and coordinate the regular instrumental observation network for the environment, including its sensitive and variable compounds such as weather, climate, glaciers and biosphere. Nowadays, with the development of information technology and sophisticated remote sensing methods, the range and diversity of environmental monitoring substantially increased, while the speed of data processing and exchange skyrocketed. Various methods of remote sensing allow undertaking valuable and real-time studies of the distant and potentially hazardous mountain lakes, glaciers, forests, land resources, etc.

The need for systematic environmental monitoring in the mountain regions became priority in the past century, when the impacts of glacier fluctuations, catastrophic floods, and mudflows increasingly affected the populated areas and infrastructure, and threatened the human safety (Orlove *et al.* 2005, Yablokov 2005). On the other hand, the importance of indirect observations decreased: living experience and knowledge of local communities and indigenous people as well as notes of travellers became less and less marginal.

In the Pamir-Alai region of Central Asia, one of the important global mountain areas, the availability of data on indirect environmental observations is modest. Yet, there are many factors, which encourage additional environmental research in this region through analysis of such non-scientific information to cover data gaps and establish links with the instrumentally observed environmental trends. Until recently, the Pamir-Alai region was not thoroughly studied and systematically monitored. Due to its relative remoteness and geographic features, the systematic instrumental environmental observation network could not cover all important locations. There are still very few regularly (and sufficiently) observed mountain glaciers and lakes, while the majority remains poorly unstudied. The remote sensing methods applied for glaciers and lakes usually pursue the specific objectives (e.g. monitoring of hazardous glacial lakes or surge-type glaciers), while the field expeditions and ground surveys are used rarely.

In addition to the direct and remote instrumental means of environmental observations, the non-scientific (popular and professional) reports available for the Pamir-Alai region provide valuable data. The spectacular mountain environments of the region (famous glaciers, peaks, lakes and other hiking destinations) attract numerous visitors, who memorize and describe their observations of the Pamir-Alai and compare it to the baseline data and previous travellers' information. Touristic and other popular maps, sketches, photographs, reports of alpinists, field notes by travellers and non-scientific manuscripts provide valuable pieces of information useful for comprehending the local and regional environmental change and raising public awareness about the impacts and consequences. The analysis of these information sources as well as communication with regular visitors and local inhabitants provide a unique opportunity to assess the state and trends of the environment in the Pamir-Alai region, to identify sensitive vulnerable natural resources and systems and to fill in the data gaps. The need for updating and popularizing the scientific knowledge is extremely important, especially in light of global climate change and its impacts on glaciers, water resources and other earth's systems. Given the fact that many small and medium-sized glaciers of the Pamir-Alai remain very poorly studied, the information collected through this research is likely to make a valuable contribution to the present-day research of environmental changes in the mountains of Central Asia, and to help increase public awareness about the driving forces of these changes and to advance similar kinds of future research.

1.2. Aims, objectives and hypothesis of the thesis

The **aim** of the research is to track evidences of environmental changes in poorly studied high altitude areas of the Pamir-Alai by analyzing the indirect non-scientific (popular) observations by the professional groups and the local communities.

To address the aim of the research, the objectives are defined as follows:

- Objective 1. Selection of the mountain regions with the lack of scientific data and sufficient availability of indirect observations reports about geographic sites/natural objects, etc.;

- Objective 2. Definition of the most relevant groups of observers, such as regular visitors (tourists, alpinists, hikers and travellers) and indigenous local people;

- Objective 3. Identification of the reference environmental objects in the neighbouring regions with the long-term instrumental records and scientific study history;

- Objective 4. Comparative analysis of the different information sources containing description of indirect observations (tourist and alpinist reports, non-scientific manuscripts, verbal communication by the local communities and travellers, visuals and photographs), and the reference objects with long-term instrumental observations.

Hypothesis of the thesis

The indirect non-scientific observations support and expand the scientific instrumental records of evidence of environmental change (glacial melting, the water level change of the mountain lakes) in the Pamir-Alai region and play the important role in public awareness about climate change impacts in the mountains of Central Asia.

1.3. Overview of methodology

The thesis is grounded on the review of numerous sources of information in the field of indirect observations. The theoretical framework of the thesis reviews the historical and modern data records and provides insights into the role of non-scientific knowledge in developing the systematic instrumental observations and applied research. The particular attention is given to the mountain environments and glaciers.

The research component of the thesis is based on the review and analysis of archival sources of information containing indirect observation records, such as tourist and alpinist notes, non-scientific manuscripts, notes of travellers, visuals relevant to the Pamir-Alai region. The descriptive manner of the qualitative research is the main approach of the study, which is also supported by unstructured interviews with the targeted groups. The period of data covers the 1930-1990, when the first solid descriptive materials by the travellers (indirect observations) became available and more recent years (1990-2008).

To compliment the findings of the research in the study area, the representative (reference) objects such as regularly observed glaciers in the neighbouring regions are carefully selected, while the instrumental hydrometeorological observations provide a basis for understanding of the climatic trends and enable the correlation of the causes and effects of the observed environmental changes in the Pamir-Alai. Throughout the research, more than 50 indirect (written) information sources have been reviewed and analysed. The interviews with 12 representatives of the professional group (tourists, alpinists and experts) and with 10 local inhabitants have been undertaken. The collection and analysis of the data using the above methods played an important role in confirmation or rejection of the research hypothesis and findings.

1.4. Limitations of the research

The main uncertainties identified during the research are attributed to insufficient availability of popular reporting on environmental change in the Pamir-Alai and certain lack of objectivity in such reporting. The key reasons of insufficient data records in indirect observations are associated with the reduced visits of tourists and alpinists to the study area in the early 1990s because of civil war in Tajikistan and unstable political and security situation in the region in general. The issue of objectivity of the popular reporting is mainly linked to the perception and personal experience factors. In many cases the travellers' (alpinists and tourists) records turned to be equally or even more reliable compared to the information provided by the local residents/indigenous people, which is possibly attributed to the population migration and the loss of local knowledge. The limitations of the study are also associated with a limited number of interviewers among the professional groups of local inhabitants (hunters, pasture grazers, farmers). The poor accessibility to communication means (telephone, internet) by this group of observers introduced major complications to the process of data collection.

1.5. Structure of the thesis

The thesis consists of the six main chapters. The first chapter presents the research subject, its aims and objectives as well as methodology and limitations. The second chapter considers the theoretical frameworks and highlights practical examples and value of indirect observations in studying the evolution of mountain environments with the focus on the Swiss Alps and the

Himalayas. Additionally, this chapter provides insights to the Pamir-Alai region and evolution of the local systematic observations of nature and climate. The third chapter elaborates on the research design and methodological frameworks. The fourth chapter summarizes observed environmental changes in the selected sites with the focus on the issue of glacier degradation and lakes' water level change. The fifth chapter discusses the research findings and possible causes and effects of environmental change in the Pamir-Alai. The final chapter provides a summary of the research results and recommendations for further studies and policy-making.

2. THEORETICAL FRAMEWORK AND BACKGROUND

2.1. Defining reporting sources and value of indirect observations

Indirect methods of research are usually referred as those, which do not imply the intentional or purposeful exploration of the phenomenon but rather rely on the reported observations of others (Wilson 2007). The methods of indirect observations were commonly used in the past, especially when the knowledge of indigenous people provided a valuable information for more detailed and thorough research. Although, it is generally accepted that the scientific data received through the direct observations is more reliable and objective, the importance of traditional knowledge as a sources of indirect observation, still plays a significant role, especially in dealing with the social and environmental issues (Mercer et al. 2007).

One of the key elements for successful collection and analysis of the indirect observations is the selection of right interview groups and reporters. The main observers/reporters, who possess traditional knowledge of the environment, are commonly found among the indigenous people and local communities. In many instances the mountain dwellers (pasture grazers, hunters and peasants) are well aware of seasonal and long-term environmental events and trends and can provide invaluable local information. In addition, non-native regular (professional) visitors to the mountain regions can provide significant contributions to the wealth of data from indirect observations. These are usually travellers, tourists, alpinists and mountain climbers (Xiao and Smith 2007).

The following subchapters discuss the role of indirect observations in the development of science with a particular focus on achievements in geography, geology and nature resource exploration in the famous mountainous global regions, such as Swiss Alps and the Himalayas.

2.1.1. The role of indirect observations in geography, geology and environmental sciences

Since the ancient times indirect observations played a key role in the development of science and technology. In the 13th century the particular attention to the importance of traditional and professional knowledge as a means of indirect observations, was attained to geography and composed the main part of geographical discoveries (Jacobs 2005). Later on, with the development of industrial revolution the indirect methods of observation served as a key component in discovering the deposits of minerals and helped to make significant progress in geology (Bolotova 2006). In environmental sciences the value of indirect observations was initially appreciated in defining the species of flora and fauna. Now the traditional knowledge receives an increasing attention in the field of biodiversity conservation and climate change adaptation (Pey *et al.* 2009, Charnley *et al.* 2007, Sillitoe and Morzano 2009).

Indirect observations helped to foster many geographical discoveries: mariners, fishermen and travellers made a great contribution to the mapping of the world's previously unknown areas. Jacobs (2005) recognizes that the notes and observations by the famous adventurer and trader, Marco Polo, played a dominant role in re-designing the world map.

The value of indirect observations and traditional knowledge was widely recognized and used in geological survey. Bolotova (2006) reports that in the Soviet Union during the era of industrialization and mining development since the 1920s, the knowledge of local people was the main initial source of information about mineral deposits and their prospects. The first attempts to explore the natural resources of the Pamir-Alai in details were made in the 1920-1930s, when the Soviet experts carefully searched for and analyzed the indirect observations by the local communities to define the valuable geological deposits in the area. The fast exploration of many deposits was successfully employed due to initial information and hints provided by farmers, hunters and shepherds (Luknitskiy 1955).

The positive effect of indirect observations always played an important role in the study of environmental systems and substantially contributed to the field research. The particular attention of the scientists received the application of traditional knowledge of local communities about flora and fauna species (Schensul *et al.* 1999). For example, the development of initial nature resource reference books, inventories of species, and maps of habitats was mostly based on indirect observations (Schensul *et al.* 1999). Even nowadays, the records of flora or fauna composition in the past (by foresters, hunters) serve as important references for comparative analysis of changes nowadays observed in the ecosystems (Korchagin 2008).

The indirect observations could also contribute to the refining and supporting evidence of the scientific research. For example, the indirect observations by the mountaineers and local communities in 2002-2008 after the disaster happened to Kolka Glacier in the Caucasus in 2002, enabled to define an alternative version of the catastrophe and resulted in more detailed description of circumstances which had provoked the collapse of the notorious glacier (Evans *et al.* 2009). In 1974 in Tajikistan, the indirect observations by the local communities played an important role in re-construction of the events prior to the ice avalanche at the Didal Glacier and made a significant contribution in studying other glaciers (Yablokov 2005).

Although the evolution of data collection and processing means significantly advanced and relies on remote sensing and computer technologies, the value of indirect observations remain essential for many types of research, especially in the regions with scarce coverage of instrumental monitoring.

2.1.2. Examples of environmental changes in the Swiss Alps and the Himalayas as defined by indirect observations

The history of incorporation of local knowledge to environmental science in the Swiss Alps dates back to several centuries, when the local people reported that the nearby glaciers, which had been steadily moved towards the village, blocked the valley and dammed the rivers to create the catastrophic floods (Orlove *et al.* 2005). The particular attention of the scientists to these transformations was recognized as the stimulus to more systematic observation of glaciers and facilitated the initiation of glaciology in Switzerland (Orlove *et al.* 2005).

The role of indirect observations of villagers, hikers and tourists has long been asserted as important in the development of trends of mountainous environment change in the Swiss Alps (Farinotti *et al.* 2009, Crate and Nuttal 2009). In 1970s, glaciologists observed that some glaciers in the Swiss Alps enlarged, whereas others substantially retreated. A decade later, a steady trend towards glacier retreat was identified as continuous. In 1991 two hikers, while travelling along the mountains, discovered Oetzi, a Bronze Age man, who perished in the mountains, and whose body remained frozen for 5 thousand years until recently, when ice melting exposed it to the open air (Orlove *et al*. 2005, Strauss 2003). Other example includes an exploration of archaeological artefacts dating back 3000 BC by a Swiss couple, who, travelling along the Schnidejoch Glacier in 2003 discovered an arrow quiver (Foulkes 2008). These findings extensively increase the knowledge of scientists about the global environmental change and stress the importance of indirect observations and data collection.

The inputs by mountaineers and local residents to the exploration of environmental changes that occurred within the well-known glaciers of the Swiss Alps are particularly interesting. The conclusion on substantial retreat of the Aletsch Glacier at present, as reported by glaciologists, is grounded on the indirect observations by local villagers for the past few centuries. Goudie (1993) mentioned that in the 13th century the glacier was very advanced as described in the local sources. However, the records of Val Bavona villagers stated that the drier and hotter summers, are the likely dominant factors in glacier retreat (Orlove *et al.* 2005). The indirect evidence of glacial melting is even more vividly reflected in visuals. The photographs and paintings of the past and present provide unique opportunities in undertaking the comparative analysis of glacier change (e.g. Grindelwald and Rhone glaciers in Switzerland).

The role of indirect observations and attraction of travellers in the personal research and better comprehension of climate change and associated impacts on glaciers advanced in the recent few years. The University of Bern in Switzerland initiated the programme of involvement of mountain tourists and hikers travelling in the Swiss Alps to record, report and understand the observed changes in the mountainous environments and in particular within the glaciers. The so-called 'climate hiking passes' along the Grindenwald Glacier, store the evidences of the past glaciation and show its rapid retreat in the last 150 years. The evidences of the glacial degradation are found not only in trimlines and moraines of the glacier, but in many touristic pictures, photographs, and sketches of the past and present, which tell the story of environmental change due to impacts of global warming (Climate Guide 2009).

The value of indirect observations was also ascertained in many scientific studies of glaciers in the Himalayas. The field notes by the British traveller Sir William Martin Conway (1894) in the Karakoram had long served as a reference for comparative analysis and research of the state of the local environment (Knight 1999, Kik 1971). The environmental changes and advances of some glaciers within the Hispar Glacier basin were reported in the Journal of Glaciology (1993) with frequent reference to the former state of snow and ice as described Conway's notes.

The above examples of traditional knowledge and notes by the travellers suggest that the value and contribution of indirect observations is high. The cases of glacier retreat and fluctuations in the Swiss Alps and the Himalayas demonstrate that indirect observations promote and support the systematic monitoring and research.

2.1. Geographic features and climatic conditions of the Pamir-Alai region

The Pamir-Alai region is one of the highest mountain systems of the former Soviet Union (Nizhnikovsky 1999a). Many peaks of the Pamir-Alai mountains exceed heights of 6000 m. asl. This mountain system is geographically linked to the Tien-Shan mountains in the north-east and the Hindukush-Karakoram mountains in the south-east and is bordered by the Fergana Valley in the north and the Amu-Darya river in the south. The major portion of the Pamir-Alai mountains is located on the territory of Tajikistan, whereas some parts stretch towards Kyrgyzstan and Uzbekistan. The Pamir-Alai consists of the Alai and Turkestan mountains along the southern Fergana Valley, Zeravshan and Gissar ranges and the Pamir mountains (Shchetinnikov 1998, Narama 2001). Scientists (Bazhev et al. 1975, Shchetinnikov 1998) divide the Pamir-Alai into two sub-regions: the Pamir and the Gissar-Alai. The highest mountains and the largest glaciers are mainly located in the central and western Pamir with its Fedchenko Glacier, one of the largest valley glaciers in the world (Shoumatoff and Shoumatoff 2000).

The climatic conditions of the Pamir-Alai region are diverse: eastern Pamir is known for its cold and arid climate (100-500 mm), while the Gissar-Darvaz mountains receive 1800-2000 mm of precipitation. The annual air temperature ranges from -18°C in winter to +10°C in summer (Tajik Meteorological Service 2009). Such great variety of the climatic conditions combined with geographic isolation promotes very reach biodiversity exceeding 3000 species of flora, including endemic and wild relatives of the domestic species, like wheat and apple, and several hundred species of fauna (Safarov and Novikov 2003).

2.2. Evolution of instrumental research in the Pamir-Alai

The exploration of the Pamir-Alai has been long considered problematic due to the remoteness and severe climate conditions of the region. The definition of Pamir was commonly associated with a 'white spot', which was usually illustrated to indicate the site on the map. The first records about Pamir date back to the 19th century, when Sven Hedin, the famous traveller, provided an illustrated manuscript describing weather, water and nature of Pamir, and depicted the ethnic and environmental peculiarities in his sketches (Hedin and Bealby 1898).

Until the late 1920s, the main methods of the research in the Pamir mountains were mostly attributed to the nature observation and field surveys. The significant advance in instrumental research occurred in the 1930s and onwards, when the Tajik-Pamir expedition gave rise to the development of a network of hydrometeorological and other observations. Remote sensing and aerial photography came to the scene later.

The following subchapters describe the first attempts of the researchers and travellers to explore the Pamir-Alai through the nature observation and field research up to the modern types of environmental monitoring.

2.2.1. Early expeditions

The first thorough investigation of the Pamir-Alai was initiated in the second half of the 19th century, when A. Fedchenko, the well-known traveller and researcher, examined the upper reaches of Zeravshan in 1868 (Yatsenko 1940, Beletsky 1970). In his further surveys Fedchenko discovered the Lenin Peak[1], Kyzylsu and Muksu Rivers and explored Pamir from the southern part of the Fergana Valley. The results of this research made a valuable contribution to the development of the first maps and sketches of the glaciers and peaks, flora and fauna of Pamir (Beletsky 1970).

The progress of geographic exploration in the Pamir-Alai continued in the 1870s with the Fergana scientific expedition, which involved several well-known astronomers, geologists,

[1] At that time the peak was named after Kaufman, the Governor-General of Turkestan (Nizhnikovsky 1999).

zoologists and topographers (Romm 1937, Beletsky 1970). One of the main tasks of the expedition was investigation and mapping of poorly studied areas in the Pamir. In 1883 the Pamir scientific expedition resulted in the exploration of the Eastern Pamir, covering the territory from the Lake Karakul to the upper streams of Pamir River (Beletsky 1970). After the 1883 Pamir expedition, the field research in the Pamir-Alai ceased without follow-up in regular observations (Yatsenko 1940).

The new wave of the Pamir research began in 1928 with the Soviet-German scientific expedition (Safarov and Novikov 2000). The main achievements were attained in geology, nature resource potential assessment and cartography. Significant progress was achieved in the development of tourism and sport. Several high peaks of the Pamir were climbed by the Soviet alpinists (Yatsenko 1940).

In 1932, the Tajik Pamir expedition made a substantial contribution in study of local flora and fauna, ecosystems, geology, hydrology, glacial areas, etc. At the same time, significant progress was made in setting up the network of instrumental observations and weather stations in the Pamir-Alai region, including establishment of the high-altitude meteorological observatory in the middle part of Fedchenko Glacier (Yatsenko 1940, IGRAN 2009). Several high mountain meteorological stations were established shortly and covered the regions of Anzob, Shahristan, Khaburobad, Sanglok, Bulunkul, Ishkashim (Mahmadaliev 2007).

2.2.2. Aerial photography and remote sensing

The development of the aerial photography and remote sensing of the glaciers in the Pamir-Alai took place since the late 1950s, when the specialists of the Institute of Geography of the Russian Academy of Science in collaboration with the Tajik glaciologists implemented the detailed cataloguing and inventory of all glaciers, including those of surge-type (Kotlyakov 1980). In the early 1990s the scientific database of the IGRAN collected the unique records of the satellite images of the Pamir and started systematic observations of the surge-type glaciers (Osipova and Tsvetkov 2003). Interpretation of the images of the past and present helped to explore the changes occurred to the surface profiles and terminus of the glaciers. In 1998, the satellite and aerial survey enabled to update the catalogue of all glaciers of the Pamir-Alai (Yablokov 2005, Dolgushin 1973).

3. RESEARCH DESIGN

My professional experience in study of climate change and glacier trends, hiking practice in the Fan Mountains and the fascinating reading of the field notes strongly motivated me to undertake the research of travellers' records, including descriptions of tours, visuals, to conduct interviews and to study correlations with systematic scientific research data on environmental trends in the neighbouring regions.

The research design of the thesis is tailored to the conditions of the Pamir-Alai region. The descriptive manner of qualitative research was the main approach of this study and included literature and archival review and interviews with the targeted groups. To compliment the findings of the research, the regularly studied objects (representative glaciers in the neighbouring regions) have been selected as a reference, while the instrumental hydrometeorological observations provided an understanding of climatic trends and enabled to correlate the causes and effects of the observed environmental changes in the study region.

3.1. Methods of data collection

3.1.1. Documentary data

The data was collected through the review of the travel and guide materials, diaries, manuscripts and field notes, illustrations, photos and touristic reports. The selection of the targeted objects within the defined areas of the research was set upon the sampling and generalization of the obtained materials. The data collection among the local population enabled to fill-in the gaps and to clarify a number of questions. In fact, the initial phase of the data collection led to more focused framing of the problem and helped to define the priorities.

In order to support the findings in relation to the observed trends of climate change, the long-term data records of hydrological, meteorological and glaciological instrumental observations were collected and synthesized in accordance with the selected reference objects of the study area. The latest materials available from international and regional sources were reviewed to define the global and regional environmental change. The publications and assessments of the national institutions as well as studies related to climate change impacts on the mountainous environment in Central Asia were sorted and analysed. A particular attention was given to the validity and reliability of data and sources.

3.1.2. Interviews

Interviews played an important role in data collection and verification of the findings. The targeted group of interviewers included alpinists and tourists, regular mountain travellers and indigenous people. Traditional and specialized knowledge defined though the interview enabled to update the data and provided on-hand experience and personal explanation of the indicators, which sometimes revealed entirely new aspects of the problem. The interviews were conducted through e-mail, telephone and personally.

The interview with experts, particularly, glaciologists, meteorologists and biologists, was another aspect of data compilation and verification. The experts were chosen according to their competence in environmental monitoring, climate change and its impacts on glaciers and water resources.

3.2. Methods of data analysis

The main research method was identification, selection and analysis of information collected by alpinists and tourists. This includes numerous data with indications and discussions of indirect evidences of environmental change (in particular glacier/permanent snow cover and lakes change) due to climate variability. The main approach was to review the manuscripts, notes and journals of the first travellers (1930-1990) and to study the notes, touristic reports and other non-scientific field materials collected in the recent period (1990-2008). The findings were compared to the climatic data and data on reference glaciers located in the area.

The data and materials obtained during the interviews and literature review helped to define differences and similarities in indirect observations by indigenous people, travellers and scientists. A summary of methods used to achieve the objectives of the research is provided in Table 3.1.

Table 3.1

Methodological frameworks of the thesis

	Objective	Methods	Results
1.	Selection and definition of the research areas within the Pamir-Alai mountainous system	Documentary data, and consultation with experts	The research areas within the Pamir-Alai mountainous system defined and selected
2.	Selection and definition of potential observers, regular visitors and interviewers among indigenous people, tourists, alpinists, hikers and travellers	Consultation with experts, review of documentary data	The potential interviewers and target group defined and selected
3.	Selection of the reference objects in the neighbouring regions, which could potentially correspond to the field observations in the research areas	Consultation with experts, review of documentary data	Reference environmental objects in the neighbouring regions defined and assessed
4.	Analysis of environmental change in the research areas and correlation with the reference objects	Documentary data, interview with target groups, consultation with experts	Potential linkages between the environmental changes occurred in research areas and reference points identified and correlated
5.	Interpretation of the research findings and discussion	Literature review, interview and consultation with experts	Potential impact of climate change on the mountainous environment of the Pamir-Alai defined Recommendations developed

3.3. Uncertainties and limitations of the research

The main uncertainties are attributed to the insufficient level of details available from the indirect reporting, questionable credibility in some cases and a limited number of interviews among the local communities.

One of the reasons of the reduced number of reports in the last few years is linked to the reduction in tourist and alpinist travels to the Pamir-Alai mountains since 1990s. This is probably due to civil war in Tajikistan and logistical constrains in the neighbouring countries. It is also understandable that in many cases tourist visits provide mostly seasonal and irregular records, which makes it difficult to study the long-term environmental trends.

The objectivity of reporting is an issue, which is related to the human perception and personal experience. In many cases records of professional travellers (alpinists and tourists, many of whom are of foreign origin) appear to be more detailed and credible compared to the information provided by the local communities.

The contact with local communities was problematic: the target group consisting of pasture grazers, hunters was not addressed because of inaccessibility and lack of communication means. On the other hand, the brief surveys conducted with the local inhabitants, living in the study areas, did not provide explicit information about the main environmental and climatic indicators and could not be clarified or revised due to the reasons mentioned above.

4. REPORTING ENVIRONMENTAL CHANGES IN THE PAMIR-ALAI

This chapter provides an overview of the reported environmental changes as they occurred in the Pamir-Alai region over the past and present periods. The main environmental objects discussed in the chapter are glaciers and selected mountain lakes, which could serve as indicators of environmental trends and effects.

4.1. General description of the study area

The study area is the high altitude region of the Pamir-Alai in Central Asia (Fig. 4.1). In the first half of the 20th century a number of alpinists, who climbed in the Lenin Peak[2] region (7134 m.asl) totalled 1600 (Nizhnikovsky 1999a), and by the present time this number may have doubled. The Kuhistoni Matcha, Iskanderkul Lake area and the Fan Mountains are the primary visiting sites for the regular mountain tourists and hikers. The Lenin Peak and other mountains attract specialized and trained people and alpinists.

The Pamir-Alai region is covered by the network of hydrological and meteorological observations. The meteorological stations located almost at all altitudes conduct instrumental observations of the climatic parameters and study hydrological conditions in the rivers and lakes. However, since the early 1990s the quality and quantity of these observations deteriorated. The collapse of the Soviet regime, civil war, lack of finance and trained personnel significantly affected meteorological and hydrological observations, and limited the glaciological field surveys of glaciers in the Pamir-Alai. After a long break there is some hope that field snow and ice research will start again. Thus, in 2005-2007 a limited number of the representative glaciers and lakes were surveyed and status reports prepared.

[2] In Tajikistan the Lenin Peak is also called Ibn Sino Peak.

Fig. 4.1
Pamir-Alai mountain region with the selected study sites
Source: Novikov 2009

In spite of intense touristic activities, the above mentioned areas (the Lenin Peak, the Kuhistoni Matcha and the Fan Mountains) are covered with limited observation programme and network of systematic monitoring. In this context, the role of indirect field observations by visitors, tourists, mountain professionals could play an essential role in comprehending the environmental trends and conditions over the time. The glaciers and lakes, which have been regularly studied (Table 4.1) are selected as reference objects for comparative analysis of changes and trends as described in the field notes and by the instrumental records. The main representative glacier for the whole region is Abramov Glacier, which is included into World Glacial Monitoring Database (maintained by the University of Zurich) and is correlated to many glaciers of the Pamir-Alai with systematic observations conducted until 1999 (UzGlavHydromet 1999).

Table 4.1

Selected regions of the study area and reference objects

Study areas	Region	Indicator	Reference point
Kuhistoni Matcha Region	Turkestan-Alai	Glaciers	Zeravshan Glacier
Fan Mountains	Gissar Mountains	Glaciers and lakes	Yakarcha Glacier
Lenin Peak region	Pamir	Glaciers	Oktyabrsky Glacier

4.1.1. Kuhistoni Matcha region, GISSAR-ALAI

The Kuhistoni Matcha region (Fig. 4.2) in the upper Zeravshan basin includes Zeravshan and Turkestan mountain ranges. The largest *Zeravshan Glacier* in the region is also a source to Zeravshan River, which has a strategic value in Central Asia.

Fig. 4.2
Kuhistoni Matcha region
Source: Novikov 2009

In this mountain region, there are two different climatic periods observed throughout the year: cold and humid (from November to April) and warm and dry (from May to October), when the fluctuations of air temperature are insignificant (Maksimov 1973). The most favourable period for tourism and alpinism is from the end of July until the end of September (Maksimov 1973, Emelyanova 1987), when the weather is steady and sunny, with rainfalls lasting not more than 1-3 days (Mikhailov 1978).

The description of climatic conditions in the Matcha region has a long history of the travellers' observations. The tourists and alpinists thoroughly depicted their observations in the field notes and travelling journals (Zigmantas 1997; Shestakov 1998). From these field reports it appears that in the past twenty-thirty years the local weather has changed towards more unstable. The increased number of cases with temperature and precipitation anomalies is reported by several travellers (Tupitsin 2009, pers. com, Kushmantsev 2007). For example, the period 1997-1998 was reported as extremely humid with severe rainfalls, while the year of 2008 turned to be extremely arid and hot (Silvestrov 2009, pers. com). Zigmantas (1997) and Monsar (2008) pointed out that intense glacier melting caused changes in the touristic pathways and typical routes. While many passes in the past were covered with snow and ice, at present they lie on the bedrock and debris.

Evident transformation of the climbing routes occurred at *Raigorodsky Glacier*. The path to the main glacier body, which had been accessible before 1990s, became impassable (Shestakov 1998) due to the increased melting and ice cracks on the glacier (Fig. 4.7). The glacier visibly retreated and is covered by rocks (Fig. 4.5, Shestakov 1998, Monsar 2008). Moreover, the alpinist paths, which were described as reliable in 1973 (Maksimov 1973), are either disappeared or changed in unrecognizable ways, mainly due to significant ice reduction and melting (Monsar 2008). In comparison with the past years, some sections of the bedrock formerly covered by the glacier became exposed to the open air and are now covered with debris (Fig. 4.3 and 4.4, Silvestrov 2009, pers. com).

Fig. 4.3
Raigorodsky Glacier in 1986
Source: Silvestrov 2009

Fig. 4.4
Raigorodsky Glacier in 2006
Source: Silvestrov 2009

Fig. 4.5
Retreat of Raigorodsky Glacier
Source: Novikov 2009

Other changes associated with glacier melting are observed in the lower part of *Raigorodsky Glacier*. The former moraine which has been previously covered with debris (in 1960-70s) and was vegetation-free now appears as an alpine meadow with grass and even small trees. The ice free area is expanding (Fig. 4.7, Monsar 2008).

Fig. 4.6
Raigorodsky Glacier: dangerous cracks

Source: Monsar 2008

Fig. 4.7
Raigorodsky Glacier: alpine meadow and juniper forest on the glacial moraine
Source: Monsar 2008

Similar trends are observed at *Shchurovsky Glacier*, one of the largest valley glaciers in the Kuhistoni Matcha. It seems that in recent years this glacier experiences a rapid melt-down and retreat. Its terminus is now positioned at higher altitude than in the past (Smirnov 2009, pers. com), whereas the lower part of the glacier body is increasingly covered with stones, ice breaks and debris (Fig. 4.9) as compared to 1987 (Mikheev 1987). The ice cracks in the glacier became so extensive and dangerous that travellers have to look for alternative bypasses and routes (Fig. 4.8, Tupitsin 2008).

Fig. 4.8
Shchurovsky Glacier: glacial breaks

Source: Tupitsin 2008

Fig. 4.9
Shchurovsky Glacier terminus: moraine and debris
Source: Tupitsin 2008

Significant changes occur to some other glaciers such as *Farahnou Glacier* and *Ak-Terek [Western] Glacier* (Fig. 4.10, Monsar 2008, Kushmantsev 2007). The number of ice cracks here reportedly increased. In 2007 Kushmantsev (2007) reported that the icefall of *Farahnou Glacier* was completely covered with the ice cracks and melted to an extent, which has not been observed before (Maksimov 1973).

Fig. 4.10
Ak-Terek [Western] Glacier: ice cracks
Source: Tupitsin 2008

Fig. 4.11
Kshemish Glacier: debris on the terminus
Source: Tupitsin 2008

The glacial degradation is reported at *Kshemish Glacier, Aksu Glacier, Tamingen Glacier* and *Birksu Glacier*. While the lower parts of these glaciers experienced visible transformation of terminus and formerly glaciated areas became rocky and dusty landscape (Fig. 4.11, Vitchak

1991, Novik 1996, Kushmantsev 2007), their upper parts are exposed to rapid melting and formation of the glacial lakes and streams. In 1996 there was one glacial lake, which was located within the moraine ‘blanket’ of *Aksu Glacier* (Novik 1996). However, in 2007 the group led by Kushmantsev (2007) noticed that the number of lakes increased to three and occupied larger surface area.

Consistent with the trends described above, the regular monitoring and scientific data suggest glacier decline in the Kuhistoni Matcha region. Observations of *Zeravshan Glacier* show that in the 20th century its area reduced by 1.2 sq. km and its terminus retreated for nearly 2 km (Makhmadaliev *et al.* 2002; Yablokov, 2009 pers. com). The research data demonstrate that the glacier melt intensified in the past 50-60 years (Yablokov 2009 pers. com, Khomidov 2009, pers. com). The melting of *Zeravshan Glacier* is associated with regional (and global) climate warming at high altitudes (as observed at the nearby Dekhavz meteorological station the annual air temperature raised by +0.4°C), in spite of little increased precipitation (Asanova 2006).

4.1.2. The Fan Mountains, GISSAR-ALAI

The system of the Fan Mountains (Fig. 4.12) is located between the Zeravshan and Gissar ranges and occupies an area of 800 sq. km (Barash 1963). The geographical position and mild climate favour the abundant natural resources and biodiversity (Zaytsev 1972). In the past there were hundreds of small glaciers commonly found on the northern slopes and dozens of crystal clear lakes (Salamatov 1978, Papagnutstsi 1968). The origin of the lakes differs; some appeared as a result of valley blockages by the rockslides, while the others formed as a result of glacial retreat (Papagnutstsi 1968, Zaytsev 1972) filling the ancient moraines.

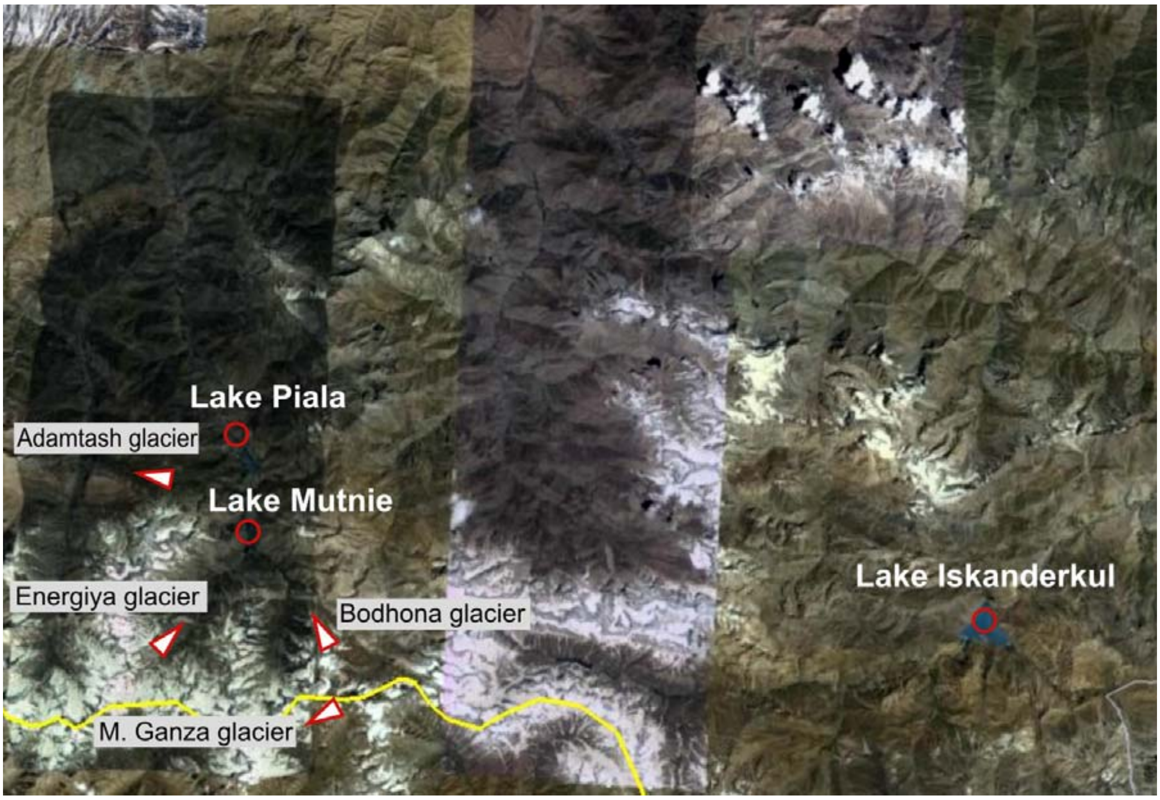

Fig. 4.12
Fan Mountains
Source: Novikov 2009

The climate conditions in the Fan Mountains have long been recognized as dry and continental (Gusev 2005). The weather in summer was usually stable with air temperatures in July reaching 27-30°C (Papagnutstsi 1968). However, in the last decades the local climate appears to be changing: the travellers report that the dry and warm season in the Fan Mountains expanded from August to September (Seriy 2009, pers. com, Ganakhovsky 2009, pers. com).

The evidence of former glaciation is present in the form of large moraines and retreated termini. Currently *Bodhona Glacier*, one of the valley glaciers in the Fany Mountains, is rapidly retreating: its moraines no longer contain a solid ice support and glacier terminus is increasingly covered with stones and debris (Fig. 4.13 and 4.14, Simonov 1991, Andreev 2002). Similar changes occur in the nearby glaciers. The intensive retreat of *Adamtash Glacier* left a long track of former ice body, and in comparison with the past years its terminus reduced by 300 m (Boshtruk 1990). It is asserted that ice cracks on the glacier surface increased (Ganakhovsky 2009).

Fig. 4.13
Bodhona Glacier: moraines and debris
Source: Fany 2005

Fig. 4.14
Bodhona Glacier: side boards
Source: Soshnikov 2006

The changes in the glaciers' surface appearance also show significant transformations. In 1937 Mukhin and Gusev (1949), discovered that *Malaya Ganza Glacier* had cracks only in its lower part. However, in the past years the surface ice cracks became widespread in the middle and upper parts of the glacier (Gazizov 2008, Gusev 2005, Ivanov 2006). The depth of some cracks, which are usually hidden under the snow cover, can reach tens of meters (Fig. 4.15, Gazizov 2008, Savenkov 2006). While the upper part of *Malaya Ganza Glacier* is covered with cracks, the lower part experiences a dramatic ice melting (Fig. 4.16, Simonov 2004). It is evident that the glacier experiences a continuous degradation.

Fig. 4.15
Malaya Ganza Glacier: hidden ice cracks
Source: Savenkov 2006

Fig. 4.16
Malaya Ganza Glacier: meltdown of ice sheets
Source: Simonov 2004

The glacier melting potentially impacts on lakes and triggers the intensive fluctuations in water levels. Since many lakes in the Fan Mountains are of glacial origin and are fed by glacial water, they quickly respond to any changes in the glaciers upstream (Makhmadaliev *et al*. 2008). It was reported that the *Lake Piala* (Fig. 4.17), a round-shaped lake, at the foot of *Adamtash Glacier* had relatively low water level in 1970s (Zaytsev 1972). However, in the recent years the volume of water significantly increased and the lake became the main camping stop for many travellers (Priboichenko 1996, Nikonorov 1998, Ganakhovsky 2004, Tikhomirova and Kornienko 2007).

Fig. 4.17
Lake Piala
Source: Mustaeva 2006

Fig. 4.18
Lakes Mutnie
Source: Simonov 2004

In contrast to the *Lake Piala*, the field observations (Ganakhovsky 2009, Seriy 2009, pers. com) of the *Lake Mutnie* (Fig. 4.18), the double-lake system located beneath *Chimtarga* and *Energiya Glaciers,* show that the water level of the lake decreased in comparison with the 1960s (Papagnutstsi 1968). The decrease of the water availability in the lake is probably attributed to the decrease of glacial water input from the surrounding glaciers, which lost their former capacity to supply enough water in view of the exhaustion of ice reserves. However, limited observation data for the *Lake Piala* does not provide the reliable conclusions on the reasons of water level fluctuations since there are several alternative explanations by mountain visitors.

The strong correlation of environmental changes in the Fan Mountains is witnessed at *Yakarcha Glacier* (3800 m. asl), which has been regularly studied by the Tajik Meteorological Service (Yablokov 2003). The instrumental climate data show that the amount of atmospheric precipitation and annual air temperatures in the region increased (Asanova 2006, Mahmadaliev *et. al* 2008). The most intensive melting of *Yakarcha Glacier* was observed in 1972-1977, when the terminus of the glacier retreated for 25 m, i.e. the pace of its retreat amounted to 5 m per year. Later on, the speed was reduced to 2-3 m per year (Yablokov 2000). Although the recent results show that *Yakarcha Glacier* does not experience dramatic melting, it is known that the body of the glacier continues to subside (Mahmadaliev *et. al* 2008, Yablokov 2006).

4.1.3. The Lenin Peak region, PAMIR

The Lenin Peak region (Fig. 4.19) is located in the north-eastern Pamir, on the border between Tajikistan and Kyrgyzstan (Nizhnikovsky 1999a). The Lenin Peak (7134 m asl.) is the third highest peak of the former Soviet Union and the highest peak of the Zaalai range, which is stretched from the west to east for 200 km (Beletsky 1970, Nizhnikovsky 1999a).

It is known that the most favourable season for mountaineering and climbing in the region is the first half of August when the local weather is reasonably stable and predictable (Foigel 2006, Potapenko 2008). However, the indirect observations by travellers in the recent years suggest that local weather conditions are probably changing. For example, the summer of 2000-2003 was characterised as much wetter comparing to 1970-1980s (Yanchevsky 2009, pers. com), whereas in 2008 the snowline was found at the altitude of 5000 m asl., i.e. 500 m higher than usual (Salnikov 2008).

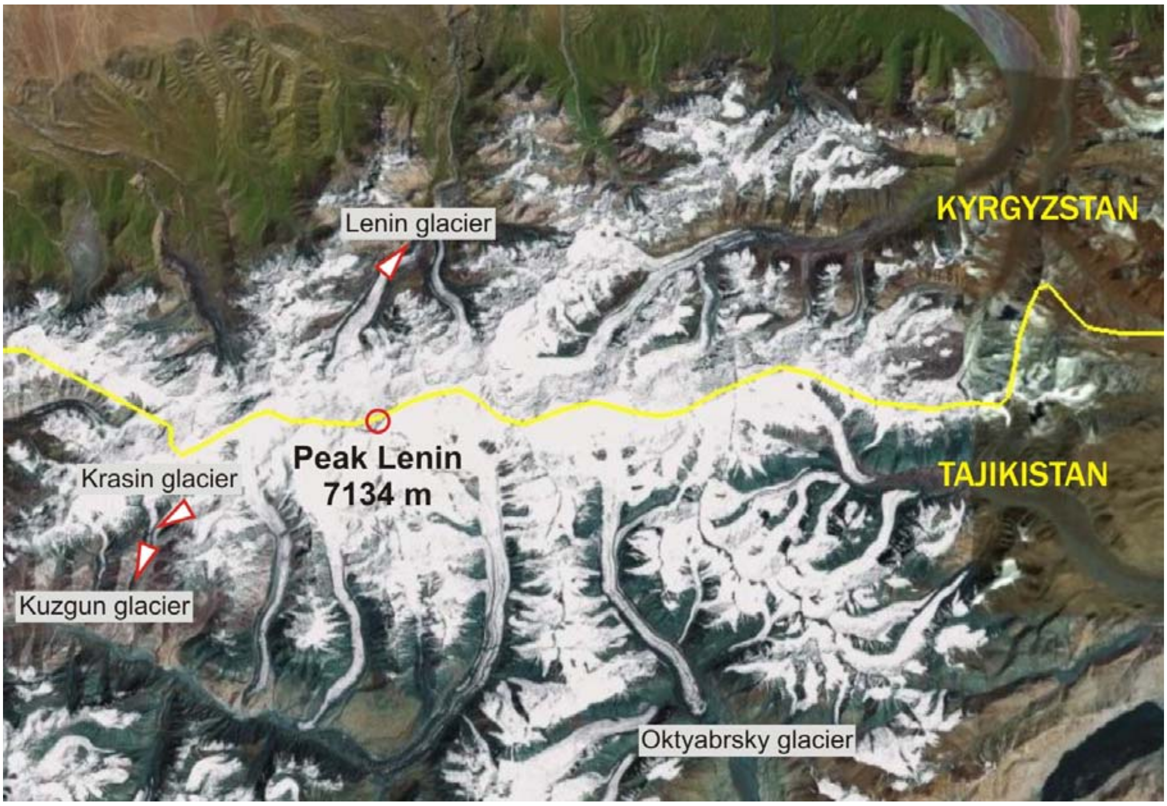

Fig. 4.19
The Lenin Peak region
Source: Novikov 2009

Many travellers (Zelentsov 2003; Salnikov 2008) recognized that in view of obvious changes in the environment, description of glaciers done in the past could hardly be compared to the present-day situation. Significant changes occurred to *Kuzgun* and *Minjar Glaciers,* which are now covered by the dead ice and separated from the main glacial body (Fig. 4.20 and 4.21).

The latter is significantly retreated and shielded in debris. The number of ice cracks also increased. Nizhnikovsky (1999) reported that ice cracks in the past were rather rare phenomena at *Minjar Glacier*. However, at present they become so numerous that the climbing and crossing the glacier became a real challenge and serious risk to life (Nizhnikovsky 1999b).

Fig. 4.20
Kuzgun Glacier: ice breaks at the terminus
Source: Kiev's Tourist Club 2008

Fig. 4.21
Kuzgun Glacier: dead ice
Source: Zelentsov 2003

More ice cracks are also observed on other glaciers. In 1936 Beletsky mentioned that there was just a few of them in the upper part of *Lenin Glacier*. However, in the late 1990, Nizhnikovsky (1999a) described that the top plateau of *Lenin Glacier* became abundant in ice cracks (Fig. 4.23). The number of glacial lakes on *Lenin Glacier* also increased (Fig. 4.22). Some changes occurred in the passes and routes within the glacier, which alpinists usually take in their climbing. For example, until 1980 many travellers used the pass along the moraine of *Lenin Glacier*. However, in the past 20 years it became inaccessible due to the increased melting of ice, numerous cracks and water discharge (Nizhnikovsky 1999a).

Fig. 4.22
Lenin Glacier: glacial lakes
Source: Andreev 2008

Fig. 4.23
Lenin Glacier: massive ice cracks
Source: Slavin 2007

Significant changes occurred to the position of glacier termini. At present, the glacier, which steppes down from the pass *Zolotoi Telenok*, is no longer connected to the *Glacier № 197* (Lebedev 2001, Vetluzhskih 2003). The glacier extremely retreated and is covered with stony bedrocks and moraines. The retreat of the glacier is observed in the Sauksay river basin. Lebedev (2001) recognized that the glacier significantly melted and formed many small glacial streams under the terminus.

While the small and medium size glaciers in the region within the Lenin Peak system undergo the process of visible degradation, quite different changes are observed at several glaciers positioned on the steep slopes. Many alpinists (Nizhnikovsky 1999a, Zelentsov 2003, Yanchevsky 2006) found out that *Krasin Glacier* (a surge-type/pulsating glacier) significantly extended its glacial body in the recent decade (Fig. 4.24 and 4.25). Formerly its bottom part was 'dead' and the vast moraines separated it from *Kuzgun Glacier*. At present *Krasin Glacier* is approaching *Kuzgun Glacier*, breaking away the massive blocks of ice (Zelentsov 2003).

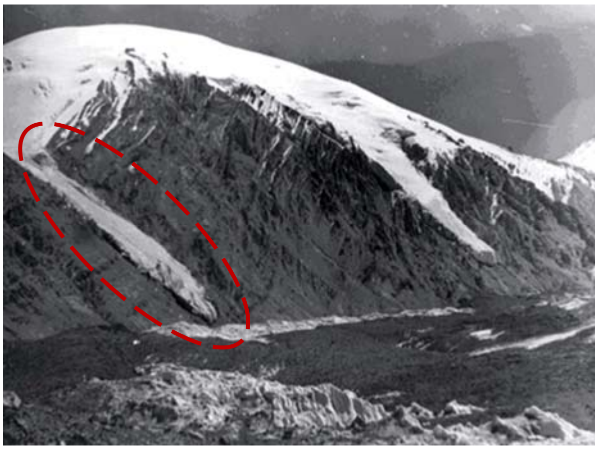

Fig. 4.24
Krasin Glacier in 1981
Source: Yanchevsky 2009

Fig. 4.25
Krasin Glacier in 2006
Source: Yanchevsky 2009

The impact of steady climate warming on the glaciers in the region was reported on *Maly Oktyabrsky Glacier* (4570 m asl.), which is representative to the above-described region. The average speed of retreat of *Maly Oktyabrsky Glacier* amounts to 10 m per year. The most intensive retreat of this glacier was recorded during 1960-1975 and totalled 150 m (Yablokov 2003). The similar rate is observed at present (Khomidov 2009, pers. com). The recent survey shows that the glacier body is prone to multiple ice cracks and glacial lakes (Khomidov 2009, pers. com).

The correlation between the increase in air temperature and glacial degradation is witnessed at another representative glacier, *Abramov Glacier* (3800 m.asl), which has the steady instrumental observations from 1967. The study showed that for the entire period of observations the glacier lost 18% of its glacial mass and retreated for 500 m (Fig. 4.26 and Fig. 4.27, UzGlavHydromet 1999, Yablokov 2003). The steady increase of air temperature and decrease in atmospheric precipitation over the last 30 years are considered as the key reasons of the glacier degradation (UzGlavHydromet 1999).

Fig. 4.26
Source: SANIGMI, UzGlavHydromet 2006

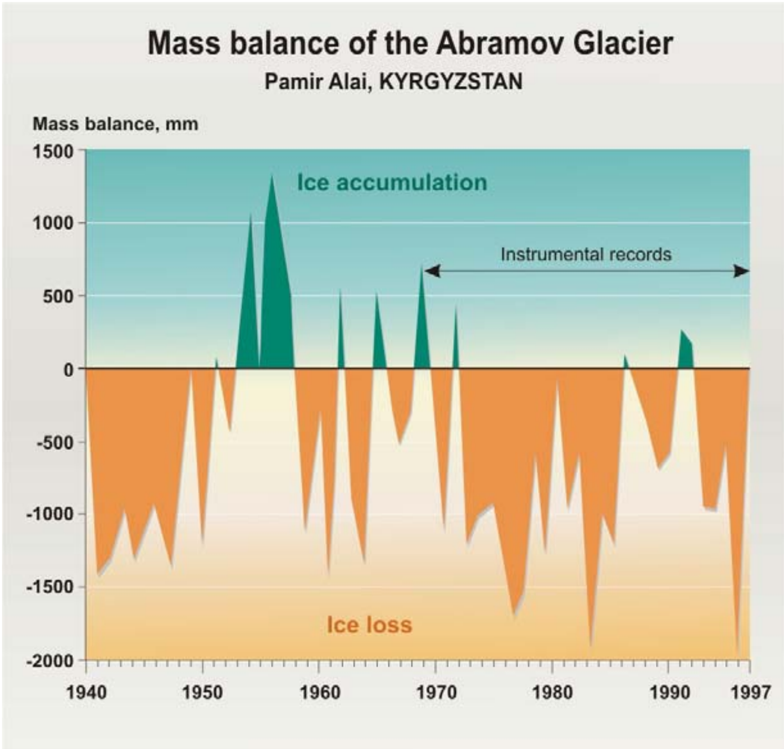

Fig. 4.27
Source: SANIGMI, UzGlavHydromet 2006

5. DISCUSSION OF THE MAIN RESEARCH FINDINGS

The results of the study show that the glaciers of the Pamir-Alai experience intensive changes, which mostly involve the retreat of glacier body, reduction of the terminus, increased exposure of bedrock, and fluctuations of the water level in the glacial lakes (Khromova *et al.* 2006). Increase in air temperatures and changes in atmospheric precipitation, which have been reported by instrumental observations over the recent decades, suggest that the observed patterns of glacier degradation are linked to climate variability and change.

5.1. Links between glacier melting and climate change

The long-term data records of the meteorological observations show that the annual mean temperature in the high altitudes increased from 0.2 to 0.4°C in the recent 50-60 years (Tajik Meteorological Service 2009). The figure 5.1 shows the trend of annual air temperature and projections for Dehavz and Fedchenko, the selected high mountain observation locations within the Pamir-Alai system. According to the numerical climate models, air temperatures in the region will likely continue to increase in the next several decades. The changes and trends in the amount of atmospheric precipitation are not uniform. The increase of atmospheric precipitation is observed in the downstream areas of Zeravshan River (12%) and Gissar and Darvaz (2%); on the contrary, the decrease in precipitation is observed in the Eastern Pamir (5-10%). The unevenness in distribution of atmospheric precipitation is mostly attributed to the individual topography of the selected regions and impacts of local and regional weather factors (Mahmadaliev *et al.* 2008, Asanova 2006).

The increase of air temperature causes glacier melting, whereas the increase in precipitation usually favours the glacial accumulation (Shchetinnikov 1998, Yablokov 2003). Although the instrumental records confirm the increase in the atmospheric precipitation in the Gissar and Zeravshan mountains, ice melting and glacier deterioration is prevalent. Experts (Khromova *et al*. 2006) explain that the increased input of atmospheric precipitation cannot compensate the loss of ice due to increased summer melting.

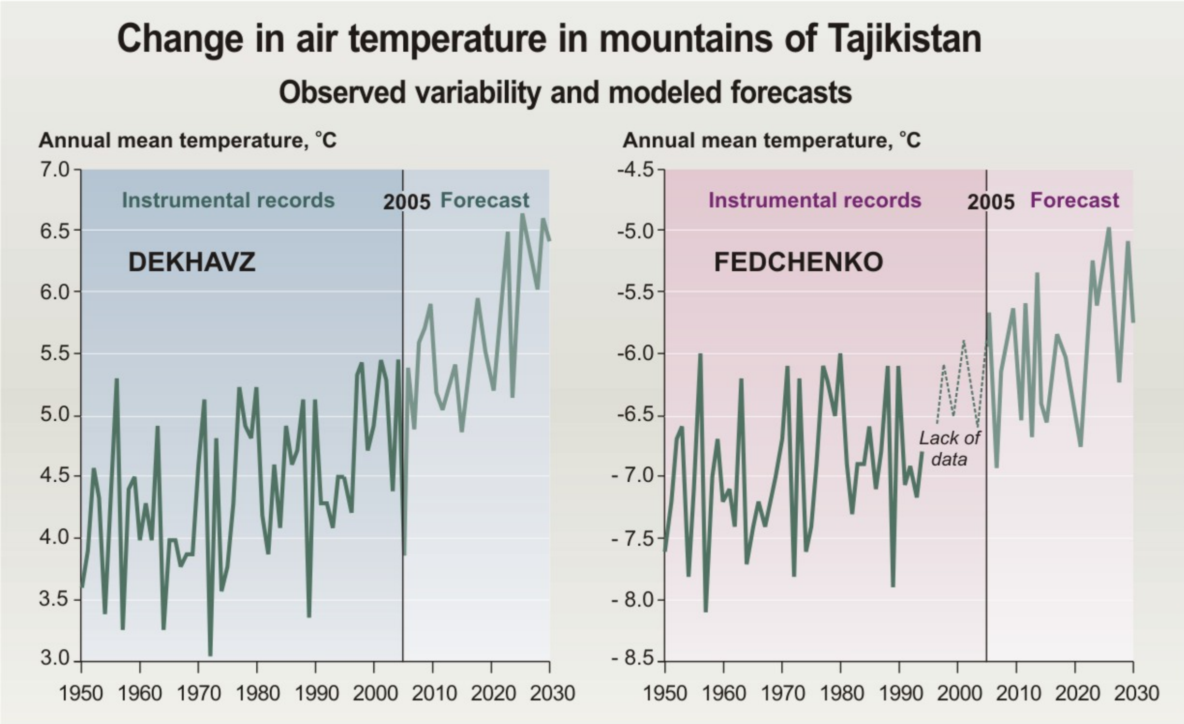

Fig. 5.1.
Source: adopted from **Mahmadaliev *et al*. 2008**

The rate of glacial degradation is linked to the surface area and elevation/exposition of the glacier. Large glaciers, like *Shchurovsky Glacier* (21.4 sq. km), experience long and steady retreat, whereas the small ones (less 1 sq. km), like *Bodhona Glacier and Malaya Ganza Glacier* are melting more rapidly. These observations correspond to the findings and projects of Yablokov (2000) and Makhmadaliev *et al.* (2002), that small glaciers are most vulnerable to climate warming.

5.2. Indicators of glacier melting and transformation

The development of moraines, debris, and the formation of glacial lakes as well as fluctuation of water level in the selected lakes are considered among the main indicators of glacier melting and transformation (Fu and Yi 2009, Khromova *et al.* 2006). Visual observations of glacier degradation in the Pamir-Alai in recent years match the global trends of glacier mass reduction and climate warming.

5.2.1. Formation of glacial lakes and fluctuation of water level in the selected lakes

The rapid melting of glaciers in the Pamir-Alai promotes formation of the increasing number of glacial lakes. The visible evidence comes from *Tamingen* and *Birksu glaciers* and numerous glacial lakes are also observed at *Lenin Glacier*. Overall, the increased rate of the glacial lakes and streams formation could be related to climate warming in the high altitudes (Haritashya *et al*. 2009).

Glacier melting has an effect not only on the formation of glacial lakes but also on water level in some regular lakes. The fluctuations of the water in the *Lake Piala* are probably associated with climate variability and change, and the state of glaciers that feed the lake basin. The increased water level in lakes due to accelerated meltdown of the surrounding glaciers corresponds to the findings of local (Mahmadaliev *et al*. 2008) and foreign (Chen *et al*. 2007, Haritashya *et al.* 2009) experts in relation to the climate change impacts in the mountain environments.

5.2.2. Moraines and debris

The moraines and debris, which are commonly found on almost all glaciers of the Pamir-Alai, suggest that the glaciers experience serious deformations. Formation of fresh moraines at several small glaciers of Gissar-Alai, like *Adamtash Glacier*, *Kshemish Glacier*, *Aksu Glacier*, implies that the degradation became more pronounced in the recent years in light of climate warming.

5.2.3. Ice breaks and cracks

The increased number of ice cracks and breaks along with the subsidence of the glacial body are evident indicators of glacier surface change and melting. The study shows that practically all glaciers of the Pamir-Alai became increasingly covered with ice cracks and breaks. In the Pamir, large *Lenin Glacier* in the foothills of Lenin Peak features vivid signs of glacial degradation. In the Gissar-Alai glaciers with increasing number of ice cracks and surface subsidence include: *Malaya Ganza Glacier*, *Adamtash Glacier*, *Farahnou Glacier*, *Ak-Terek Glacier* and *Shchurovsky Glacier*.

5.2.4. The present behaviour of surge-type glaciers

The present behaviour of the selected surge-type glaciers such as *Krasin Glacier* suggests the state of advance in comparison with the early 1980s. Zelentsov (2009, pers. com) asserts that the recent advance of *Krasin Glacier* is caused by the accumulation of critical snow-ice mass (primarily because of intense atmospheric precipitation during 2000-2005) in the circus of the glacier, which pushes down to the main glacier body via icefall and makes such a visible advance. Yanchevsky (2009, pers. com) indicates that the advance of the glacier is probably attributed to the typical surging behaviour, especially after 2005 (the period of intensive solar radiation), which is linked to the glacier melting and under-ice water formation which further promotes rapid sliding of the glacier mass down the slope. Thus, the visual enlargement of the glacier does not necessarily mean that the glacier is growing.

In general, the issue of glacier surging and its driving factors is not thoroughly studied in the Pamir-Alai (Yablokov 2005, Osipova and Tsvetkov 1998). Therefore, we cannot claim that the recent advance of the selected surge-type glaciers is strongly attributed to climate warming.

5.3. Potential risks associated with climate change impacts on glaciers

Since the glaciers play a key role in river runoff, the observed changes have a potential to affect the hydrological balance. The projections by local experts (Makhmadaliev *et al*. 2002, Mahmadaliev *et al*. 2008) indicate that climate change may cause the intensive degradation and melting of many glaciers in the 21st century. It is expected that the short-term consequences of ice melting would be associated with the increased number of water-related disasters in the form of floods, mudflows, GLOFs, etc., and could present real risks to the livelihoods and economic stability of the region. In the long-term, the deficit of water resource availability and due to reduced input of melt water by glaciers is expected. As water has a strategic value for the Amu-Darya and Syr-Darya basin states where the Pamir-Alai mountains serve as water towers, the issue of water deficit could challenge the environmental security and even trigger the conflicts (Novikov 2004). Therefore, it is important to address the potential risks associated with glacier degradation and water resource reduction and develop policies, which duly integrate early warning and environmental monitoring. A list of more detailed recommendations is provided in the concluding chapter of the thesis.

The glacial melting and the loss of snow cover has a potential impact on mountain biodiversity because of alteration of the typical conditions at specialised habitats and cause biodiversity loss and species migration. In recent years, the evident change in the composition and distribution of mountain biodiversity, including substantial reduction of the endemic marmot (*Marmota Menzbieri*) population in the northern Pamir (Mahmadaliev *et al*. 2008) is reported due to combination of several factors.

5.4. Concluding remarks

The research findings show that in most cases data provided by the travellers (alpinists and tourists) through the indirect observation of environmental change in the Pamir-Alai corresponds to the trends reported by instrumental observations at the reference sites. Due to inaccessibility of the region (high altitude zone) and the lack of instrumental observations, the indirect method of environmental study in the Pamir-Alai is highly valuable. For more comprehensive research it is suggested to enlarge the area of the study region and to include mountain shepherds, pasture grazers and hunters to the group of interviewers.

The table below provides an overview of environmental changes observed and reported indirectly in the Pamir-Alai region in the past years.

Table 5.1

Overview of the indicators of the environment change in the Pamir-Alai mountains

Indicators	Sites of indirect observations	Reference glacier	The identified trends
Number of glacial lakes and outflows	Lenin Glacier** Tamingen Glacier* Birksu Glacier* Aksu Glacier*	Abramov Glacier Oktyabrsky Glacier	**Increasing**
Terminal parts of the glaciers	Raigorodsky Glacier* Kshemish Glacier* Aksu Glacier* Adamtash Glacier* Bodhona Glacier* Shchurovsky Glacier* Malaya Ganza Glacier* Glacier № 197**	Abramov Glacier Yakarcha Glacier Zeravshansky Glacier	**Retreating**
Number of ice cracks and glacier surface change	Lenin Glacier** Kuzgun Glacier** Minjar Glacier** Malaya Ganza Glacier* Adamtash Glacier* Farahnou Glacier* Ak-Terek Glacier* Shchurovsky Glacier*	Abramov Glacier Yakarcha Glacier Zeravshansky Glacier Oktyabrsky Glacier	**Increasing, Surface subsiding**
Behaviour of the surge-type glaciers	Krasin Glacier**	-	**Variable, state of advance for some**
	Lake		
Fluctuation of water level in the selected lakes	Lake Piala* Lake Mutnie*	Yakarcha Glacier Zeravshansky Glacier	**Increasing Decreasing**

*** Gissar-Alai mountains**
**** Pamir mountains**

6. CONCLUSION AND RECOMMENDATIONS

The final chapter summarizes the main research findings and provides several recommendations for enhancing the state of environmental knowledge and observation systems in the Pamir-Alai mountain region using the indirect observations.

6.1. Conclusion

The main research findings suggest that indirect observations could play an important role in exploring the environmental changes in the Pamir-Alai mountain region similarly to other global mountainous climate-sensitive areas. It is shown that in the conditions of rare and incomplete instrumental observations in the mountain environments and serious lack of the field reports and information about the current state of glaciers in the Pamir-Alai region, the indirect observations enable to fill-in the gaps in knowledge and to complete the picture of environmental change as it occurs in the studied area. Based on the indirect observation records and consultations with the local communities and national/international travellers and experts, the study area covers several most visited touristic sites in Central Asia: the Kuhistoni Matcha, Fan Mountains and the Lenin Peak.

The written records of regular visitors (tourists, alpinists, hikers, research travellers) as well as personal communication with the local inhabitants (residents of small remote areas) provide valuable pieces of information for comprehending trends and changes in the environmental conditions of the Pamir-Alai.

Significant changes occur to the touristic routes in snow-covered and glaciated areas. The rapid melting of glaciers, increased number of glacial lakes, retreat of terminus and degradation of body of many glaciers serve as reliable indicators of environmental change in the Pamir and Gissar-Alai in the recent years. Similar trends are observed in the reference glaciers. The study confirms that the glaciers of the Gissar-Alai (Kuhistoni Matcha and the

Fan Mountains) retreat more rapidly comparing to the glaciers around the Lenin Peak, which is possibly associated with their smaller surface size and lower elevation.

The research shows that indirect observations provide valuable contribution to the framework research of the mountain environments of the Pamir-Alai region. Similar methodology and target groups could be used for field research in the upper Amu-Darya River basin, which possesses many unstudied glaciers and has irregular network of observations.

6.2. Recommendations

Based on the research findings, the following recommendations have been elaborated:

1. Integration of indirect methods of environmental research with the modern methods and systems of instrumental environmental observations and monitoring. It is advisable to integrate the indirect/voluntary observations with the modern technological means of data compilation and supplement the existing instrumental observation networks. This integrated approach will improve the public participation of environmental changes in the mountainous areas, provide better access to the traditional knowledge and stimulate researchers to undertake further studies.

2. Development of early warning systems to prevent the potential risks, associated with environmental change and glacier melting in the high mountains of the Pamir-Alai. Based on the findings of the thesis it is necessary to undertake further in-depth studies of the identified glaciers and lakes. The early warning systems would enable to systematically observe and timely report about potential risks posed by GLOFs, floods or droughts and support climate change adaptation strategies.

3. Encouragement of collecting and reporting the indirect observations in the Pamir-Alai by the visitors, tourists, alpinists, and local inhabitants. It is necessary to encourage the

professional groups of travellers to carefully record/picturize the changes observed in the Pamir-Alai and report about the potential risks and hazards associated with these changes to the responsible public bodies and the general public. Such a feedback will promote further development of the systematic monitoring and instrumental research (e.g. surge-type glacier, glacial lakes, etc.), and help to address the possible impacts in near real time manner. On the other hand, it would be feasible to introduce the new international experience for public awareness in the key touristic destination[3] and to promote volunteer observation activities on climate and environmental change in the mountainous regions, and develop networking with regional institutions.

<u>4. Enhancement of cooperation with touristic and alpinist associations active in the Pamir-Alai in communicating the indirect observations.</u> Improved networking and collaboration with touristic and alpinist associations in maintaining the database of travelling materials (maps, photographs, non-scientific materials), could help in raising awareness and increase the knowledge of environmental trends in the mountainous regions of Central Asia.

<u>5. Raising awareness of policy makers, scientists, and local residents about environmental change in the high mountains of the Pamir-Alai</u>. It is important to implement programmes on raising public awareness on global, regional and local environmental change in the mountain regions, particularly in the Pamir-Alai and target the various groups of audience: policy makers, researchers, and the public at large.

[3] For example, the initiative of the University of Bern described in previous chapter

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ANNEX I

List of interviewers

Name	Institution, affiliation	Area of expertise
Valentina ASANOVA	Meteorologist, climate change expert, Tajikistan	Climate change analysis, trend and prognosis in Tajikistan
Aleksander YABLOKOV	Glaciologist, field researcher, climate change expert, Tajikistan	Impacts of climate change on glaciers and natural disasters in Tajikistan
Anvar KHOMIDOV	Glaciologist, field researcher, climate change expert, Tajikistan	Impacts of climate change on the glaciers of Tajikistan
Viktor NOVIKOV	Environmental specialist, UNEP, Geneva	Mountainous ecosystems, climate change, environmental security in Central Asia
Vladimir TUPITSIN	Alpinist, mountain traveller	Mountainous environment of the Pamir-Alai
Ilya SILVESTROV	Alpinist, mountain traveller	Mountainous environment of the Pamir-Alai
Oleg MONSAR	Alpinist, mountain traveller	Mountainous environment of the Pamir-Alai
Evgeny SMIRNOV	Alpinist, mountain traveller	Mountainous environment of the Pamir-Alai
Sergei SERIY	Alpinist, mountain traveller	Mountainous environment of the Pamir-Alai
Sergei GANAKHOVSKY	Alpinist, mountain traveller	Mountainous environment of the Pamir-Alai
Oleg YANCHEVSKY	Alpinist, mountain traveller	Mountainous environment of the Pamir-Alai
Dmitry ZELENTSOV	Alpinist, mountain traveller	Mountainous environment of the Pamir-Alai

ANNEX II

List of questions

1. What is the rate of the tourist visits to the Pamir-Alai?
2. How frequently do you visit the region of interest (Kuhistoni Matcha region, Fan Mountains, the Lenin Peak region)?
3. What type of climatic conditions have you and your team experienced in the recent 10 years in the mountains of the Pamir-Alai?
4. How has changed the glacial and snow conditions of the Pamir-Alai in the previous and last visits to the region?
5. What glaciers of the Pamir-Alai (Matcha region, Fan Mountains, the region of the Lenin Peak) have experienced the major transformations in the recent years?
6. What type of glacier transformations have served as the main indicators of the glacier change (glacial lakes, ice cracks, retreat of the terminus, change in vegetation, etc.)?
7. What type of documentary data can serve as evidence of the glaciers transformation?
8. Did you notice any transformations in the mountainous routes and travel passes in the Pamir-Alai? If yes, what are the main reasons?
9. What do you think the main reasons of Krasin Glacier's advancing? How did the climatic conditions of the last years impact on its status?
10. What were the main information sources and reference guide of your travels to the Pamir-Alai?