RUSSIAN GEOGRAPHICAL SOCIETY

FACULTY OF GEOGRAPHY,
LOMONOSOV MOSCOW STATE UNIVERSITY

INSTITUTE OF GEOGRAPHY,
RUSSIAN ACADEMY OF SCIENCE

Vol. 10 2017 No. 03

GEOGRAPHY ENVIRONMENT SUSTAINABILITY

EDITORIAL BOARD

CONTENTS

Ekaterina Rets[1], Julia Chizhova[2], Nadine Budantseva[3], Natalia Frolova[3], Maria Kireeva[3], Nadezda Loshakova[3], Igor Tokarev[4], Yurij Vasil'chuk[3]
[1]Water Problems Institute, Russian Academy of Sciences, 119333, Russian Federation, Moscow, ul. Gubkina 3
[2]IGEM RAS, 1190176 Russian Federation, Moscow, Staromonetniy per., 35
[3]Lomonosov Moscow State University, Moscow, Russia. 119991, Russian Federation, Moscow, GSP-1, Leninskie Gory, Faculty of Geography
[4]Center for Geo-Environmental Research and Modeling (GEOMODEL) at St. Petersburg University. 198504, Russian Federation, St. Petersburg, Ulianovskaya st., 1.
*** Corresponding author:** Ju. Chizhova (eacentr@yandex.ru)

EVALUATION OF GLACIER MELT CONTRIBUTION TO RUNOFF IN THE NORTH CAUCASUS ALPINE CATCHMENTS USING ISOTOPIC METHODS AND ENERGY BALANCE MODELING

ABSTRACT. Frequency and intensity of river floods rise observed in the North Caucasus during last decades is considered to be driven by recent climate change. In order to predict possible future trends in extreme hydrological events in the context of climate change, it is essential to estimate the contribution of different feed sources in complicated flow-forming processes in the alpine part of the North Caucasus. A study was carried out for the Djankuat River basin, the representative for the North Caucasus system. Simultaneous measurements of electrical conductivity, isotopic and ion balance equations, and energy balance modeling of ice and snow melt were used to evaluate the contribution of different sources and processes in the Djankuat River runoff regime formation. A forecast of possible future changes in the Djankuat glacier melting regime according to the predicted climate changes was done.

KEY WORDS: stable isotope, electrical conductivity, Caucasus, alpine river, hydrograph separation

CITATION: Ekaterina Rets, Julia Chizhova, Nadine Budantseva, Natalia Frolova, Maria Kireeva, Nadezda Loshakova, Igor Tokarev, Yurij Vasil'chuk (2017) Evaluation of glacier melt contribution to runoff in the North Caucasus alpine catchments using isotopic methods and energy balance modeling. Geography, Environment, Sustainability (GES Journal), Vol.10, No 3, p. 4-19
DOI-10.24057/2071-9388-2017-10-3-4-19

INTRODUCTION

There is an urgent need for improving our understanding of the controls on water sources and flow paths in high mountainous systems. Floods are observed in the North Caucasus during the spring-summer period and are usually caused by superimposition of heavy rainfall on intensive melting wave. The same factors bring about other various hazardous natural processes in this region, such as debris flows, avalanches, and glacier lakes outburst floods. In the beginning of the XXI century, frequency and intensity of dangerous hydrological processes in the North Caucasus was much higher then during the previous years, which is usually associated with recent climate change (Rets and Kireeva 2010; Semenov and Korshunov 2008; Seynova 2008).

The main tendencies in recent climate change in the North Caucasus include an increase in mean annual air temperature due to both summer and winter period and decrease in the number of days with negative air temperature in the plain territory. A gradual rise in mean annual air temperature has been registered during the entire observational period (since the 1930s); however, the intensity of this process has increased dramatically since 1986. The linear trend of the mean annual temperature increase for the period from 1986 till now varies from 0.5–0.7ºC in ten years in the north-east of the plain territory to 0.7–0.8ºC in the south-east of the plain territory.

In central and eastern mountainous part of the North Caucasus, a decrease in mean annual temperature was registered from the beginning of the observational period (1940s–1960s) to the early 1990s. The mean annual temperature value fluctuations have become stable since the end of the 1980s–the beginning of the 1990s; for some meteorological stations, the upward tendency was manifested.

A substantial spatial heterogeneity of long-term fluctuations of the precipitation characteristics was observed, especially in plain territories during summer. Consequently, long-term fluctuations of the annual precipitation sum show multidirectional tendencies. A statistically significant rise in the annual precipitation sum was observed during the entire observation period at most of the sites located in the western part of the study area. In the central and southern parts, the statistically insignificant increase was quite common. Cyclical fluctuations of the annual precipitation sum are characteristic of the driest eastern part of the North Caucasus.

An important indicator of climate change within the study area is a long-term regime of glaciers in the North Caucasus. Degradation of glaciers indicates a trend of climate warming since the end of the XIX century.

General glacier retreat in the North Caucasus started in the late 1840s, with four to five minor readvances in the 1860s-1880s and three readvances or steady states in the XX century (1910s, 1920s, and 1970s-1980s). Since the last Little Ice Age maximum in the middle of the XIX century, most glaciers have decreased in length by more than 1000 m, and the rise in the elevation of the glacier fronts has exceeded 200 m (Solomina et al. 2016). At present glaciation is in a regressive phase, and the overall reduction is about 20% of the area of the 1970s (Seynova 2008). The observed tendencies of climate change and deglaciation clearly explain the ongoing increase of extremeness of hydrological regime in the North Caucasus. On the one hand, a rise in mean annual temperature provokes an increase in the glaciers melt rate and, hence, a drawdown in long-term ice reserve and rise in the overall water flow in the region. On the other hand, an increase in precipitation sum contributes to the process through more frequent rain flooding.

Modeling of extreme hydrological events and prediction of possible future trends in the North Caucasus are difficult due to complicacy of flow-forming processes. An extremely complicated structure of river flow feed is characteristic of high-altitude territories that play a definitive role in the formation of hydrological regime in the North Caucasus. The following components can be distinguished: (a) ice and firn melting in accumulation and ablation zones of glaciers; (b) seasonal snow melting on glacier covered and non-glacier area of watersheds; (c) liquid precipitation; and (d) underground waters. In addition, each of these components can run off the watershed surface in different ways.

According to this, estimation of the contribution of different feed sources to flow forming processes is essential to understanding the mechanism of flow formation and the genesis of the extreme hydrological events in the North Caucasus. One of the advanced approaches to study the hydrological cycle and the response of glaciers to climate change is the stable isotopes method (Vasil'chuk et al. 2013).

Consequently, oxygen isotopes can be applied to determine the timing and origin of changes in water sources and flow paths, because different water sources often have isotopically different compositions due to their exposure to different isotopic fractionation processes (Yde et al. 2016).

Since the 1970s, this technique has been widely used for hydrograph separation (Dinçer et al. 1970) and then a series of papers was published, describing runoff hydrograph separation by nourishment sources with the use of 18O (Fritz et al. 1976; Hermann et al. 1978; Herrmann and Stichler 1980; Martinec et al. 1974; Meiman et al. 1973; Mook et al. 1974; Sklash and Farvolden 1979).

Most often a conceptual two-component mixing model is applied, where an old-water component (e.g., groundwater) is mixed with a new-water component (e.g., snowmelt), assuming that both components have spatial and temporal homogeneous compositions. The general mixing model is given by the equation

$$QC=Q_1C_1+Q_2C_{2+}\dots Q_nC_n$$

where the discharge Q and the isotopic value C are equal to the sum of their components. The water isotope mixing models can provide valuable information on spatial differences in hydrological processes on diurnal to annual timescales (Ohlanders et al. 2013; Kendall et al. 2014; Wang et al. 2015).

In glacier-fed river systems, the principal water sources to bulk run-off are associated with ice melt, snowmelt, rainfall, and groundwater components. Depending on the objectives of the study and on the environmental setting, hydrograph separation of glacial rivers has been based on assumed endmember isotope mixing between two or three prevailing components. In detailed studies it may even be necessary to divide a main component, such as ice melt, into several ice facies sub-components (Yde and Knudsen 2004, Yde et al. 2016).

STUDY AREA AND PREVIOUS RESEARCH

The study was carried out in the Djankuat River basin, chosen as representative for the North Caucasus, in course of the International Hydrological Decade (IHD, 1964-1974).

Djankuat glacier (43.2°N, 42.75°E) is located on the northern slope of the Main Caucasian Ridge in the Elbrus area (Fig. 1); it is a small (9.09 km2) high-altitude river basin with mean elevation of 3285 m and glaciation ratio of about 0.5. The glacier system of the Djankuat River basin is represented by 4 glaciers: a typical valley glacier Djankuat and 3 small glaciers (Visyachiy, Viatau, Kojavgan) (Fig. 1). The lower limit of glaciation is at 3230 m. Complex observations in the Djankuat River basin started in 1965 under the IHD and have been carried out without interruptions until now (Lednik Dzhankuat 1978). Recently, the observations are carried on by the Glaciological and Hydrological departments of Lomonosov Moscow State University (MSU).

A tendency of the glacier's passage from a quasi-stationary state to degradation up to the end of the XX century identified based on direct measurements and data on changes in the hypsometry of Djankuat glacier (Aleinikov 2001; Popovnin and Petrakov 2005). The overall retreat of the glacier tongue from 1968 to 2000 was 105 m, the process, in general, being extremely uneven.

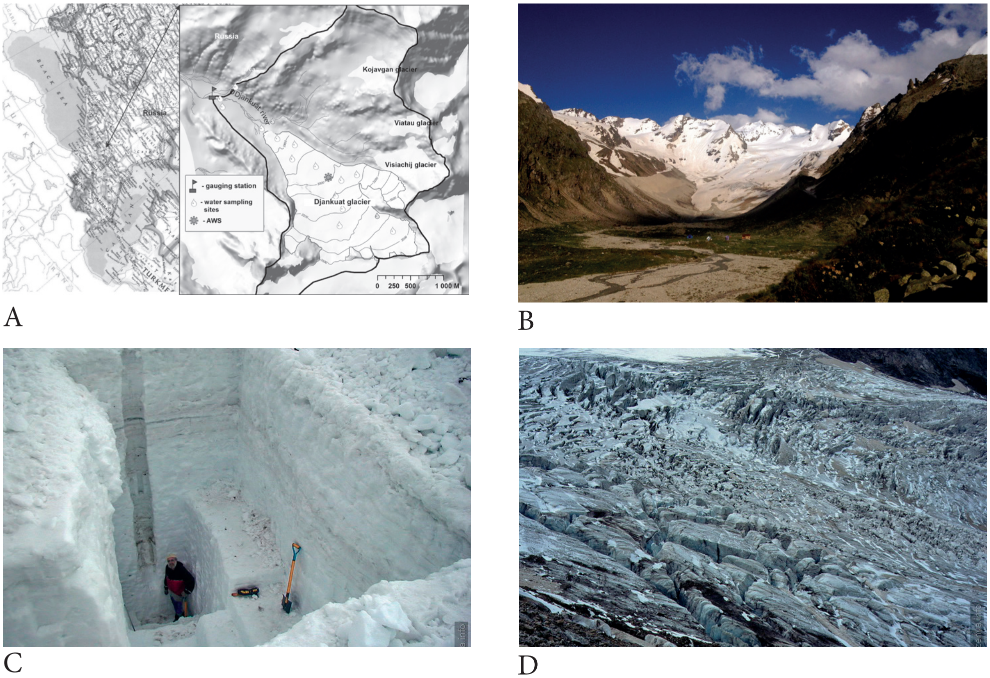


Fig. 1. The Djankuat river basin (a), view of the valley, photo by N. Loschakova (b), snow pit in the middle of the Djankuat glacier, photo by E. Nosenko (c), cracking zone in the middle of the Djankuat glacier, photo by E. Nosenko (d).

For the Djankuat basin a distributed model of snow and ice melting in high altitude zones has been applied for the ablation season of 2008 (Rets et al. 2014). The model is based on the up-to-date measurements and is focused on hydrological processes modeling in relatively small high-altitude catchments.

Ice/snow melting calculation is based on the surface heat balance equation. The input data are represented by the results of complex meteorological observations, including global short-wave radiation, incoming long-wave radiation, wind speed, air temperature vs altitude profile, dates of snowfall, DEM, and cartographic information about snow line dynamic and debris cover. The components of heat balance are distributed over the regular net with the assigned resolution.

Comparison of the calculated and measured melting depth and the ablation stakes net showed that the developed model gives correct results for all parts of the glacier. No systematic deviation is observed, even in condition of inaccurate location of the stakes. The correlation coefficient is 0.96.

The simulation results were compared to the Djankuat River discharge measurements at the gauging station (Fig. 1). The Djankuat River hydrograph during ablation in 2008 had a typical for glacial rivers saw-tooth shape with pronounced daily maximum and minimum (Fig. 2 a). In (Golubev 1976) was proposed a term "rapid runoff" to determine the component of glacial rivers flow, forming a range of diurnal fluctuations in water level. The river flow component with a much longer lag-time was called "underlying flow." Comparison of the daily volume of runoff with the total melting in the Djankuat basin allows, first of all, drawing a conclusion that not all melt water is discharged from the catchment area of the river during the ablation season (Fig. 2 b). This is mostly due to congelation processes and melt water storage in natural regulating reservoirs on the watershed that feed the Djankuat River flow during winter period (Golubev 1976). In general, diurnal snowmelt waves in areas of the watershed with a significant snow

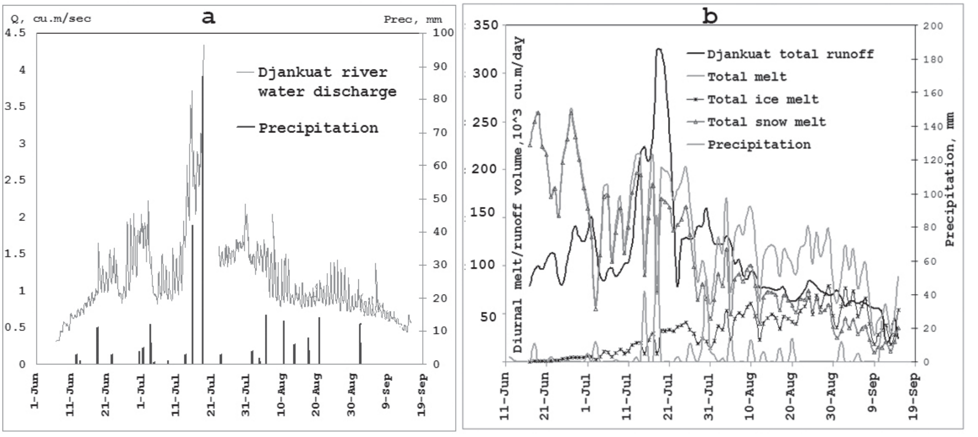


Fig. 2. The Djankuat river hydrograph in the ablation period of 2008 with one-hour step (a) and one-day step (b) in comparison with the precipitation regime and melting rate (b)

cover depth are strongly flattened in the course of lag. Time required for percolation through a 4–6 meters of snow cover can be, depending on the physical properties and characteristics of the process of melting, from 5–7 to 15–18 days (Rets et al. 2014). Further time lag of meltwater from the firn zone of Djankuat glacier to the gauging station in late July – early August, according to the estimates of (Golubev 1976), is about 5 days. As a result, against a background of general synchrony of the total daily melting and runoff there is a significant scatter of the points on the corresponding empirical dependence (Fig. 3 a). At the beginning of the ablation period, when snow cover depth is maximum, the total melting in the watershed is much larger than the total runoff (Fig. 2 a, b), and the dependence of the daily volume of runoff on the total melting is not even expressed (June points in Fig. 3 a).

Thus, runoff fluctuations show a delay and relatively higher smoothness compared to the dynamics of melting. A considerable degree of inertia in runoff processes from the basin is reflected by high values of the autocorrelation coefficient. In-row coherence can be traced up to 1 week. The autocorrelation coefficient of daily volumes of runoff with 1 day shift is 0.95, with 2 day shift – 0.87, 5 days – 0.64. The maximum release of water accumulated by the glacier is reached in mid-July, which causes an overall increase in the Djankuat River flow in this month and an excess of the runoff volume over the melting volume (Fig. 2 a,b).

A diurnal fluctuation range of runoff, the so-called "rapid runoff," is formed by meltwater part with the basin lag time of about 3–4 hours in June and July and 2–3 hours in August and September (Golubev 1976; Lednik Dzhankuat 1978). According to studies (Golubev 1976; Rets et al. 2014), this component most likely corresponds to melting on the Djankuat glacier tongue. The second component involved in the formation of a day-to-day variation in glacial river runoff is snow melt on the non-glacierized part of the watershed. An average slope time lag of meltwater runoff through the surface sediments mass to the channel network in the Djankuat River basin is from 15–16 to 25–35 hours (Rets et al. 2014). Thus, an overlay of diurnal waves of meltwater with relatively rapid lag is occurring in the Djankuat River basin. This process is reflected in the fact that the dependence of daily "rapid runoff" volume on daily volumes of melting on the Djankuat glacier tongue has a character of a family of curves (Fig. 3 b). The points fall on the upper curve in the periods of a respectively intensive melting, and on the lower one after periods of cold weather.

The distributed model of snow and ice melting permits also simulation of changes in the glacier-derived liquid runoff responding to the anticipated climate change and progressive deglaciation. If the counter-radiation of the atmosphere increases by 1.5 W/m2 (which corresponds to the changes that have occurred over the last 100 years), the mean air temperature will increase by 4°C (according to the forecast of IPCC – Intergovernmental Panel on Climate Change), the debris cover will increase will by 180% (equal to the changes, occurred from 1968 to 1999), the atmosphere transparency index will decrease by 5%, and the Djankuat glacier melting rate will increase by 12–40%, depending on an elevation-slope zone of the glacier. Thus, as area of the glacier is expected to diminish, an increase in the glacier melting volume will not be dramatic. If the area decreases by 30%, which corresponds to the changes that occurred from 1910 to 1999, a decrease in the volume of Djankuat glacier melting will be 8%.

MATERIALS AND METHODS

The observation program in the Djankuat River basin includes: 1) measurements of meteorological parameters by means of AWS Campbell Scientific CR-1000 (Fig. 1); 2) air temperature measurements in several elevation points by 3 TinyTag temperature loggers with 1-hour time step; 3) complex glaciological observations: snow course surveys at the maximum snow storage period, comprised of 250 evenly distributed measurement points, observation on the ablation stakes net (50–55 stakes throughout the Djankuat glacier area); snow density measurements, carried out in 3 representative pits every 15–20 days; and 4) the Djankuat River runoff and conductivity measurements on the gauging station (see Fig. 1). Water level was recorded with hourly motion by an automated level recorder ADU-02 and Solinst. A rating curve was electrical conductivity and was measured by a field conductometer Econics-Expert 5 times daily.

In 2013 and 2014, the program also included daily collection of water samples for natural stable isotopes analysis at the Djankuat River gauging station (90 samples in 2013, 242 water samples in 2014) (Fig. 1). The $\delta^{18}O$ values of river water at the end of the 2013 ablation period, when the glacier melting was completely finished, are taken as isotope composition of the ground water component. Liquid precipitation was sampled at every event in 2014 (31 samples) and once in 2013. Ice, firn, and snow sampling sites were evenly distributed over the river basin (overall, 9 samples were taken in 2013 and 58 samples, in 2014). The samples from the corresponding sites were taken several times during the ablation season. A vertical structure of isotopic composition of snowpack was studied in 3 representative snow pits on the Djankuat glacier in June, July, and August 2014.

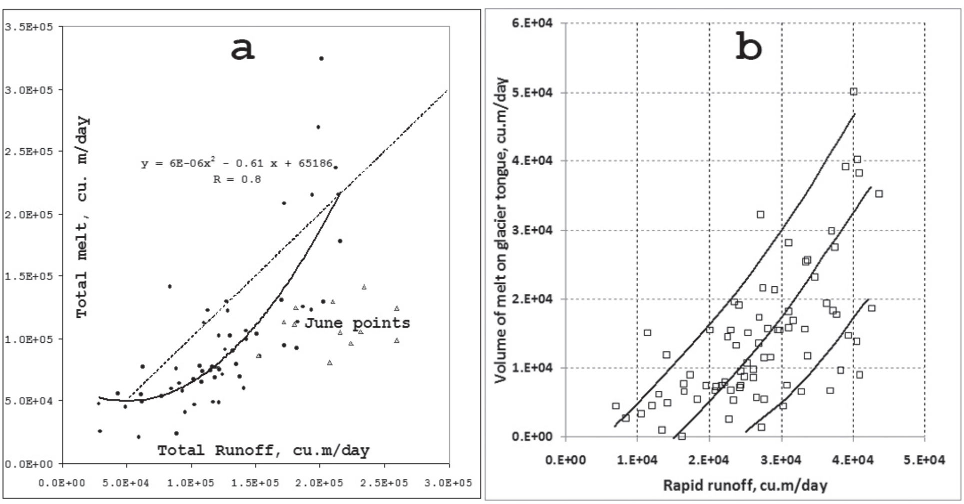


Fig. 3. Dependence of the total Djankuat river runoff on the total melt in the watershed (a); dependence of rapid runoff on melting on Djankuat glacier's tongue (b)

All samples collected in the curse of the study were measured by a Finnigan Delta-V isotope ratio mass spectrometer in the Stable Isotope Laboratory, the Department of Geography, MSU.

The isotope composition data were expressed conventionally as δ-notion (‰), representing deviation in parts per thousand, relating to the isotopic composition of V-SMOW (Vienna Standard Mean Ocean Water). International standards V-SMOW2, GISP, SLAP2, and a proprietary MSU laboratory standard (snow glacier Garabashi: $\delta^{18}O$ = –15.60‰) were used daily for the calibration measurement. The measurement precision for $\delta^{18}O$ was ±0.1‰. Measurements were made in He continues flow regime; time of equilibration sample with CO_2 was 24 hours by 24 °C. Concurrently, isotopic determinations were made in the Saint Petersburg State University Resource Center for Geo-Environmental Research and Modeling (GEOMODEL) by Picarro L-2120i. The analytical results that have been obtained independently by the two laboratories are similar; the mean difference in the definition for the same sample does not exceed 0.2‰. For final modeling the mean values (rounded to the whole number, without decimals) were taken.

SEPARATION OF THE ALPINE RIVER HYDROGRAPH USING STABLE ISOTOPES AND CONDUCTIVITY

The seasonal dynamics of water isotope composition of the Djankuat River and its runoff components show appreciable variations. The values of water $\delta^{18}O$ in 2013 varied from –11.27 to –15.04‰. The value of $\delta^{18}O$ in the Djankuat water in 2014 varied from –9.1 to –13.3‰ (Fig. 4).

In the ablation period of 2013, $\delta^{18}O$ values of the Djankuat river water show a general monotonic increase from –14.75 to –14.85‰ in early June, to –11.8 to –12.8‰ in late September. This regularity is typical of glacier rivers and originates from the considerable contribution of melting of isotopically light winter snow in the first half of the ablation season. The isotopic composition of glacier runoff within a day in June 2013 varies insignificantly: the values of $\delta^{18}O$ changed by less than 1‰ from –15 to –14‰.

In 2014, heavy spring snowfalls resulted in the formation of a thick layer (~1–1.5 m) of isotopically heavy snow, overlying winter snow. Because of this, the isotopic composition of the snowmelt runoff in 2014 is appreciably heavier and the seasonal variations are not typical: the minimums of $\delta^{18}O$ values, determined by the melting of winter, isotopically "cold" snow, can be seen only after the predominantly melting of spring snow deposits, i.e., from the second half of June to late July. The further regular shift of the isotope composition of the Djankuat River water toward heavier isotopes is due to the increasing share of ice and firn melting and liquid precipitation in the structure of glacier nourishment. Thus, the mean value of $\delta^{18}O$ was –12.06 in June 2014, –12.44 in July, –11.50 in August, and –11.7‰ in September. Thus, in 2014, the oxygen isotope composition of melt flow shows nearly no seasonal melting regularity because of the specific weather conditions in 2014, i.e., abundant spring snowfalls.

The method of isotopic markers coupled with hydrochemistry method allows solving various problems in study of mechanisms of runoff formation in mountainous river basins. Simultaneous solution of isotopes, ion, and water balance equations allows estimating seasonal dynamics of various genetic components of river flow (Williams et al. 2009).

Alpine rivers in the North Caucasus are characterized by a multicomponent feed structure and complexity of flow-forming processes. That causes rather complex regularities of isotope and ionic composition (electrical conductivity) formation.

The most positive isotope values are typical of liquid summer precipitation. The mean ™^{18}O value in collected samples of rain water was –4.7‰ (Table 1). Winter snow had the most negative isotope values (from –19.0 to –12.3‰ for $\delta^{18}O$).

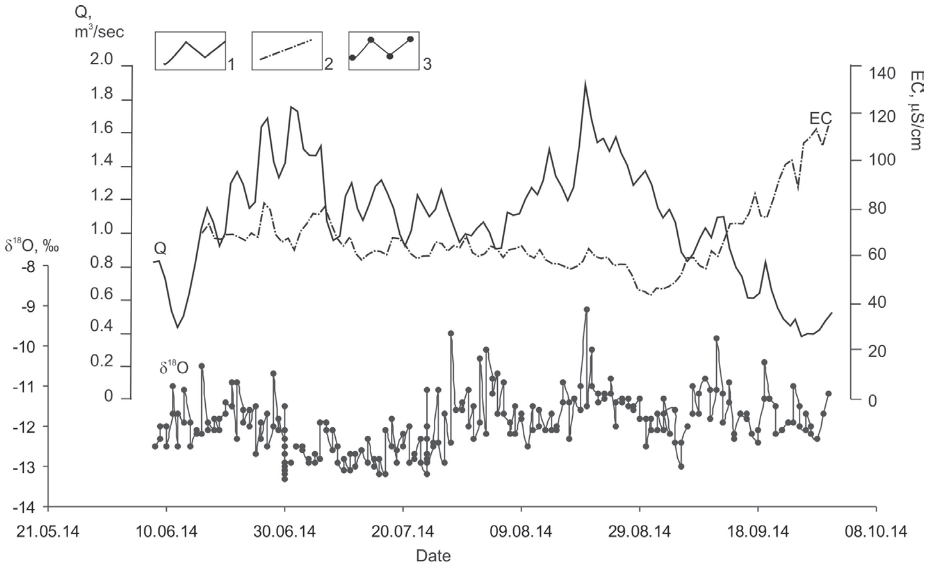


Fig. 4. Variations of the total discharge Q (1), electrical conductivity EC (2), and $\delta^{18}O$ values (3) in the Djankuat river water during the ablation period 2014

Temporal fluctuation of combination of these components in river flow forms river water isotope composition regime. Rather dry winter and anomalously high spring snowfalls observed in the study area in 2014 influenced greatly isotope composition regime of the Djankuat River during ablation period 2014. Hence, it was rather heavy compared to the previous year's samples, especially in June 2013 (Chizhova et al. 2014).

Unlike oxygen isotope, ion composition is a nonconservative characteristic; it can show how the water ran down the watershed. The part of water that ran down over a glacier surface and then through stream channels doesn't get enriched with dissolved salts and has a relatively low mineralization, not substantially different from the original values (Table 1). Ground water and water that ran down over a non-glacier surface, filtrating through comminuted surficial deposits, is significantly greater enriched with dissolved salts, which is expressed in the value of electrical conductivity. Estimated conductivity of this component reaches 105 μS/cm (Table 1).

Due to complexity of water flow feed structure in alpine conditions, an electrical

Table 1. The $\delta^{18}O$ values and conductivity in components of river runoff in 2014

	Winter Snow	Spring Snow	Firn	Ice	Rain	Ground-water
Average $\delta^{18}O$, ‰	-14.6	–7.3	–7.3	–12.8	–4.7	–11.5
Range of variation $\delta^{18}O$, ‰	–12.32… –19.0	–6.76 … –7.68	–7.64… –13.75	–9.65 … –14.36	–1.2… –11.7	–11.13 … –11.89
Average Conductivity, μS/cm	11.6	8.67	13.3	15.1	12.3	96.7
Range of variation	6.4…33.5	7.36…9.71	6.14…22.5	9.8…39.6	-	83.2…105

conductivity and $\delta^{18}O$ balance equation was derived for seasons, when it is possible to neglect some of the components in order to obtain a needed number of variables (Vasil'chuk et al. 2016, Chizhova et al. 2016).

In the end of the ablation season (Mid-August – September), it is possible to neglect the seasonal snow component, as it is generally almost completely melted away by this time. Thus, the following system can be drawn:

$$\begin{cases} \delta^{18}O = (q_i + q_f)\delta^{18}O_{if} + q_{gr}\delta^{18}O_{gr} + q_p\delta^{18}O_p \\ q_i + q_f + q_{gr} + q_p = 1 \\ M = (q_i + q_f)M_{if} + (q_{gr} + q_p)M_{gr} \end{cases} \quad (1)$$

where indexes i, f, gr, and p denote ice, firn melt, ground water, and liquid precipitation; parameters without indexes refer to the Djankuat River water, q is a share of each component in total runoff, and M is conductivity.

Solution of linked (b) and (c) equations in system (1) provided opportunity to estimate the base flow share in the Djankuat River runoff for days without significant precipitation. In September 2014, it varied from 30% to almost 100%. Calculated ground water discharge for this period was practically constant (0.45, on average, from 0.36 to 0.64 m^3/sec, Fig. 5). Value of ground water discharge for the days with significant precipitation is interpolated, which is admissible due to high level of persistence of this component of river flow. Further, the co-solution of (a) and (b) equations with the known value of groundwater allows separating the melt and precipitation components in the total Djankuat River runoff (see Fig. 5). Runoff

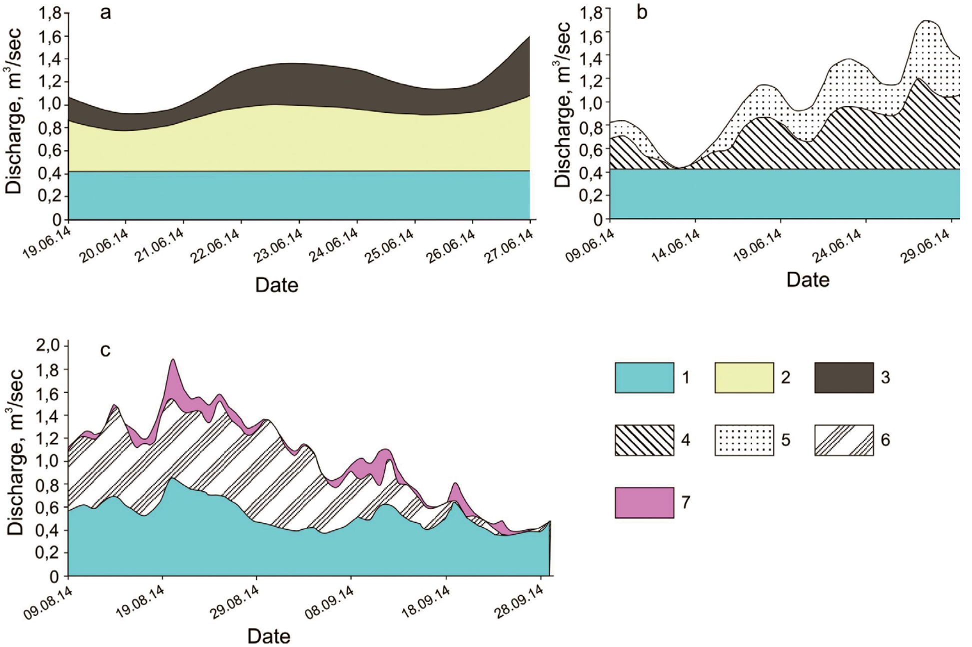


Fig. 5. The Djankuat River hydrograph separation: a – for June 2014 using ionic balance equation (2), b – for June 2014 using isotope balance equation (3), c – for September 2014 using system of equations isotope, ion and water balance (1) from (Vasil'chuk et al. 2016): 1 – base flow, 2 – snow melt on non-glacier territory 3 – snow melt on glacier, 4 – winter snow melt, 5 – spring snow and precipitation, 6 – ice and firn melt, 7 – precipitation.

formed due to ice and firn melting gradually decreases to the end of the ablation period and runs dry in late September. That illustrates process of seasonal melt water resources drainage from the Djankuat River basin at the end of the ablation season.

An unessential difference in isotope composition of firn and ice in terms of ™^{18}O does not make an attempt to separate this components by solving the system (1) credible.

spring snow had a substantial share in the Djankuat River runoff in June 2014 (15–20%). That makes it possible to conclude that under the condition of dry winter 2014, if not for heavy spring snowfalls, river runoff in the region in 2014 would be lower than the long-term average.

For the middle phase of ablation period (July), such a system of balance equations cannot be solved due to the insufficient number of equations allowing to eliminate one or the other variable.

$$\begin{cases} M = q_{sn}^{G1} M_{sn} + (q_{sn}^{NGI} + q_{sr}) M_{gr} \\ q_{sn}^{GI} + q_{snc}^{NGI} + q_{gr} = 1 \end{cases} \quad (2)$$

$$\begin{cases} \delta^{18}O = q_{snw}\delta^{18}O_{snw} + q_{snc}\delta^{18}O_{snc} + q_{gr}\delta^{18}O_{gr} \\ q_{snw} + q_{snc} + q_{gr} = 1 \end{cases} \quad (3)$$

The corresponding system of balance equations for the beginning of ablation period (June) is more complex. Two different systems should be drawn in the context of ionic balance and isotope balance:
where qsnGI and qsnNGI are shares of snow melt in the glacierized and non-glacierized parts of the watershed and qsnw, qsnc are shares of warm and cold snow melt, correspondingly.

Here we assume, firstly, that ice melt is insignificant for the beginning of ablation period and can be neglected, secondly, that the snow melt water, running down over a non-glacierized surface, filtrating through comminuted surficial deposits is enriched with salts to the rate of ground water, on average.

The system (2) can be solved if we exclude one variable; for example, we can accept the ground water discharge to be similar to the ground water discharge in August. Then, a section of the Djankuat River hydrograph in June 2014 can be divided in base flow (25–40% during the concerned period), snow melt on the glacierized part of the watershed (40–45%) and snow melt on the non-glacierized part of the watershed (15–30%) (Fig. 5).

The same assumption allows solving the system (3). According to the results (Fig. 5),

CONCLUSIONS

New results on alpine rivers water regime formation were obtained, which is extremely important in the context of increase in extremeness of the hydrological regime in the North Caucasus. The study was carried out for the Djankuat River basin which was chosen as representative of the North Caucasus during the International Hydrological Decade.

For two seasons (2013 and 2014), the isotopic characteristics of the Djankuat snowmelt runoff have been identified. Superposition of lag waves of different components of river flow results in a complex shape of the alpine river hydrograph. Application of the energy balance model of snow and ice melt with distributed parameters allowed identifying the Djankuat River runoff response to glaciers melt regime and seasonal redistribution of melt water. The diurnal amplitude of oscillation of the Djankuat River runoff in the days without precipitation is formed by melting at almost snow-free areas of the Djankuat glacier tongue. Snowmelt water from the non-glacierized part contributes to the formation of the next-day runoff. A wave of snow and firn melt in upper zones of the glacier flattens considerably during filtration through snow and run-off over the surface and in the body of the glacier. This determines a general significant inertia of the Djankuat River runoff, reflected in high rates of autocorrelation and a considerable scatter of the points on the curve of dependence of daily runoff on the total daily melting. Not all meltwater reaches the gauging station during the ablation season. Some part of melt water is stored in natural regulating reservoirs of the watershed that supply the Djankuat River flow during winter.

Simulation of changes in the glacier-derived liquid runoff responding to anticipated climate change and progressive deglaciation has shown that if the counter-radiation of the atmosphere increases by 1.5 W/m^2, the mean air temperature will increase by 4°C, the debris cover will increase by 180%, the atmosphere transparency index will decrease by 5%, and Djankuat glacier's melting rate will increase by 12–40%, depending on an elevation-slope zone of the glacier. Intensification of glacier melting can dramatically affect the occurrence of dangerous hydrological phenomena in the North Caucasus. With the decrease in area of glaciers in the Djankuat River basin after the increase in melt water recourses at some certain level a decrease will start. If Djankuat glacier shrinks by 30%, which corresponds to the changes that occurred from 1910 to 1999, a decrease in the volume of Djankuat glacier melting will be 8%.

Due to complexity of water flow feed structure in alpine conditions a solution of the ionic and δ18O balance equation was carried out for the seasons, when it is possible to neglect some of the components in order to reach a needed number of variables. A substantial excess of ™^{18}O content in spring snow over winter snow allowed distinguishing this component in the Djankuat River runoff in June. It was rather significant in ablation period of 2014 due to anomalously high spring snowfall that year. Unlike δ^{18}O, mineralization is a non-conservative characteristic; it can show how the water ran down the watershed: over the glacier surface and then through stream channels or over a non-glacierized surface, filtrating through comminuted surficial deposits. Solution of the conductivity balance equation allows identifying the base flow component in the Djankuat River runoff in August and separating the glacierized snow melt component from snow melt on the non-glacierized part of the watershed.

In general, the isotopic hydrograph separation showed that in June 2014, melting spring snow contributed about 15–20% to the Djankuat River runoff; on some days, the input of this component reached 36%. The contribution of winter snow melting ranged from 20% in the beginning of the month to 50% at the end of June 2014.

For August-September 2014, the contribution of groundwater ranged from 30% to almost 100%, the contribution of rainfall ranged from 0 to 30% (an average of 6% for the period), and the part of melt water from the firn and ice was between 0–70% (average 38.6%).

In further study we plan to use other natural markers, such as hydrogen isotope composition and macrocomponents of hydrochemical composition in order to meet the needed number of balance equations in a system to perform a full hydrograph separation.

ACKNOWLEDGEMENTS

The authors are grateful to Popovnin V., Gajdamukha M., Suchilina Z., Lavrenov A., Pozhidaeva D., Smirnov A. and Rostiashvili A. for the assistance in field work.

This work was supported by the Russian Science Foundation (№ 14-27-00083-P– Chizhova J., Budantseva N., Vasil'chuk Yu.K.; № 14-17-00155 – Frolova N.L., Kireeva M.; № 14-17-00766 – Tokarev I.) and the Russian Foundation for Basic Research (RFBR project nos. 16-05-00977 and 16-35-60042).

REFERENCES

Aleinikov, A. (2001). Vzaimosvyaz' dvizheniya gornogo lednika i yego balansa massy na primere lednika Dzhankuat, Tsentr. Kavkaz [Interrelation between mountain glacier motion and its mass balance: case study of the Dzhankuat glacier, Central Caucasus]. Avtoreferat diss. kand. geogr. nauk. M.: MGU [Extended Abstract of Cand. Sci. (Geogr.) Dissertation, Moscow: Moscow State Univ]. 24 p. (in Russian)

Chizhova, Yu., Budantseva, N., Rets, E., Loshakova, N., Popovnin, V. and Vasil'chuk, Yu. (2014). Variacii izotopno-kislorodnogo sostava talogo stoka lednika Dzhankuat na Central'nom Kavkaze [Isotopic variation of runoff from the Dzhan Kuat glacier (Central Caucasus)]. Vestnik Moskovskogo Unviersiteta, Seriya Geografiya. No. 6. pp. 48–56. (in Russian)

Chizhova, Ju., Rets, E., Vasil'chuk, Yu., Tokarev, I., Budantseva, N. and Kireeva, M. (2016). Dva podhoda k raschetu raschleneniya gidrografa stoka reki s lednikovym pitaniem s pomoshch'yu izotopnyh metodov [Two approaches to hydrograph separation of the glacial river runoff using isotopic methods]. Led i Sneg. 2016. Vol. 56. N2. pp. 161–168. DOI: 10.15356/2076-6734-2016-2-161-168 (in Russian with English summary)

Dincer, T., Payne, B., Flowkowski, T., Martinec, J. and Tongiorgi, E., (1970). Snowmelt runoff from measurements of tritium and oxygen-18. Water Resour. Res., vol. 6, pp. 110–124.

Fritz, P., Cherry, J., Weyer, K. and Sklash, M. (1976). Storm runoff analyses using environmental isotopes and major ions, in Interpretation of Environmental Isotope and Hydrochemical Data in Groundwater, Panel Proc. Ser. – Int. Atomic Energy Agency, Vienna: Int. Atomic Energy Agency, pp. 111–130.

Golubev, G. (1976). Gidrologia lednikov [Hydrology of glaciers]. Leningrad: Gidrometeoizdat, 248 p. (in Russian).

Hermann, A., Martinec, J. and Stichler, W. (1978). Study of snowmelt-runoff components using isotope measurements in Modeling of Snow Cover Runoff, Colbeck, S.C. and Ray, M., Eds., Hanover, U.S. Army Cold Regions Res. Eng. Lab, pp. 288–296.

Herrmann, A. Stichler, W. (1980). Groundwater-runoff relationships. Catena, vol. 7, pp. 251–263.

Lednik Dzhankuat: Tsentr. Kavkaz [Dzhankuat Glacier: Central Caucasus], Boyarskii, I.Ya, Ed., Leningrad: Gidrometeoizdat, 1978. 184 p. (in Russian).

Martinec, J., Siegenthaler, U., Oeschger, H. and Tongiorgi, E. (1974). New insights into the run-off mechanism by environmental isotopes, Proc. Sympos. Isotope Tech. in Groundwater Hydrol., Vienna: Int. Atomic Energy Agency, pp. 129–143.

Meiman, J., Friedman, I. and Hardcastle, K. (1973). Deuterium as a tracer in snow hydrology, The Role of Snow and Ice in Hydrology. Proc. Banff Symp., September, 1972, UNESCO-WHO-IASH, Int. Association of Sci. Hydrol. Association, Publ. 107, pp. 39–50.

Mook, W., Groeneveld, D., Brouwn, A. and Van Ganswijk, A. (1974). Analysis of a runoff hydrograph by means of natural 18O, in Isotope Techniques in Groundwater Hydrology, Proc. I.A.E.A. Symp., Vienna: Int. Atomic Energy Agency, pp. 145–156.

Ohlanders, N., Rodriguez, M. and McPhee, J. (2013). Stable water isotope variation in a Central Andean watershed dominated by glacier and snowmelt. Hydrol. Earth Syst. Sci., N. 17, pp.1035–1050, doi:10.5194/hess-17-1035-2013.

Popovnin, V. and Petrakov, D. (2005). Lednik Dzhankuat za minuvshie 34 goda (1967/68–2000/01) [Dzhankuat glacier in the past 34 years (1967/68–2000/01)]. Materialy Glyatsiol. Issled., N. 98, pp. 167–174. (in Russian with English summary).

Rets, E. and Kireeva, M. (2010). Hazardous hydrological processes in mountainous areas under the impact of recent climate change: case study of Terek River basin. Global Change: Facing Risks and Threats to Water Resources: proc. of the Sixth World FRIEND Conference. IAHS Publ. 340. pp. 126–134.

Rets, E., Kireeva, M. and Loshakova, N. (2014). Ispolzovanie teplo-balansovoy modeli dlya issledovaniya osobennostey formirovania stoka lednikovoy reki (na primere basseyna ruch.Djankuat) [Energy balance model application in studies of the glacial river runoff formation (the Djankuat basin case study)]. Eurasian Union of Scientists (ESU) № IV, pp.97–103. (in Russian).

Semenov, V. and Korshunov, A. (2008). Rajonirovanie territorii Rossii po opasnosti vysokih navodnenij v svyazi s izmeneniyami klimata [Zoning of the territory of Russia in terms of dangerous river floods in the context of recent climate change]. Upravlenie Vodno-resursnymi Sistemami V Ekstremalnykh Usloviiakh: Mezhdunarodnaia Konferentsiia, 4-5 Iiunia 2008 G., Moskva Sbornik Dokladov [Water Resource Systems Management Under Extreme Conditions International Conference, 4-5 June 2008, Moscow Conference Proceedings], pp.142-145. (in Russian).

Seynova, I. (2008). Climatic and glaciological conditions of debris flow formation in the Central Caucasus at a stage of regress of the little ice age. In: Debris Flows: Disasters, Risk, Forecast, Protection (ed. by S. S. Chernomorets). Pyatigorsk, Russia, pp.121–124.

Sklash, M. and Farvolden, R.N. (1979). The role of groundwater in storm runoff. J. Hydrol., vol. 43, N. 1–4, pp. 45–65.

Solomina, O., Bushueva, I., Dolgova, E., Jomelli, V., Alexandrin, M., Mikhalenko, V. and Matskovsky V. (2016). Glacier variations and high resolution paleolimatic reconstructions in the Northern Caucasus in the past 500 years. Global and Planetary Change, vol. 140, pp. 28-58. http://dx.doi.org/10.1016/j.gloplacha.2016.02.008

Vasil'chuk, Yu.K., Budantseva, N., Vasil'chuk, A. and Chizhova, Ju. (2013). Isotopnie metody v geografii. Chast' 3. Geochimiya stabilnih isotopov atmosphery i gidrosphery [Isotope Ratios in the Environment. Part 3: Stable isotope geochemistry of atmosphere and hydrosphere]. M.: Geographicheskiy fakultet MGU. [Moscow, Department of Geography, Lomonosov Moscow State University]. 216 p. (in Russian).

Vasil'chuk, Yu., Rets, E., Chizhova, Ju., Tokarev, I., Frolova, N., Budantseva, N.A., Kireeva, M.B. and Loshakova, N.A. (2016). Hydrograph Separation of the Dzhankuat River, North Caucasus, with the use of Isotope Methods. Water Resources, Vol. 43, №6, pp. 847–861. doi: 10.1134/S0097807816060087

Williams, D., Cable, J. and Ogle, K. (2009). Tracing glacial ice and snow meltwater with isotopes. WRP final report, May 1, 2009, 9 p. Source: http://www.uwyo.edu/owp/_files/finalreportp19.pdf

Wang, X., Li, Z., Ross, E., Tayier, R. and Zhou, P. (2015). Characteristics of water isotopes and hydrograph separation during the spring flood period in Yushugou River basin, Eastern Tianshans, China. J. Earth System Sci., vol. 124, N. 1, pp. 115–124.

Yde, J. and Knudsen, N. (2004).The importance of oxygen isotope provenance in relation to solute content of bulk meltwaters at Imersuaq Glacier, West Greenland. Hydrol. Process., N.18, pp.125–139.

Yde J., Knudsen N., Steffensen J., Carrivick J., Hasholt B., Ingeman-Nielsen T., Kronborg C., Larsen N., Mernild S., Oerter H., Roberts D. and Russell A. (2016). Stable oxygen isotope variability in two contrasting glacier river catchments in Greenland. Hydrol. Earth Syst. Sci., 20, pp.1197–1210.

Received on Novembre 09th, 2015 Accepted on August 10th, 2017

Rets Ekaterina, PhD in geography, Research Associate, Water Problems Institute. Her main scientific interests are mountain hydrology, modeling of hydrological processes, and programming. Ekaterina Rets is highly involved in several project on representative alpine river basins in the North Caucasus and Central Asia, field work in alpine areas, and teaching a course in mountain hydrology. Her goal is to investigate poorly understood mechanisms of flow formation and origin of dangerous hydrological processes in mountainous areas.

Chizhova Julia, PhD in geography, Senior Researcher of the Laboratory of Isotope Geochemistry and Geochronology, IGEM RAS. In 2007 she began her employment in the mass-spectrometry laboratory. Her research interests are associated with the use of stable isotopes in permafrost, meromictic lakes, glacier ice, snow, and glaciers research, and isotope study of origin of hydrological processes in mountainous areas. She is a co-author author of research monograph and text book "Stable isotope geochemistry of atmosphere and hydrosphere" published in 2013 in the series "Isotope Ratios in the Environment".

Budantseva Nadine, PhD in geography, Senior Research Scientists of the Department of Landscape Geochemistry and Soil Geography of the Lomonosov Moscow State University. In 2007 she began her employment in the mass-spectrometry laboratory. Her research interests are associated with the use of stable isotopes in ice wedge, pingo, lithalsa, massive ice, meromictic lakes, and glaciers research, and isotope study of the origin of hydrological processes in mountainous areas. She is a co-author of research monograph and text book "Stable isotope geochemistry of atmosphere and hydrosphere" published in 2013 in the series "Isotope Ratios in the Environment".

Frolova Natalia, DSc in Geography, Professor of the Department of Hydrology of the Lomonosov Moscow State University. Member of the IAHS, a Member of the Hydrological Commission of the International Geographical Union. Scientific interests: estimates and forecast of river flow, dangerous hydrological processes, and mountain hydrology.

Kireeva Maria, PhD in geography, Senior Researcher of the Department of Hydrology of the Lomonosov Moscow State University. Her main scientific interests are mountain hydrology, modeling of hydrological processes, and programming.

Loshakova Nadezhda, a first year Master program student of the Lomonosov Moscow State University, Department of Hydrology. Her main scientific interests are mountain hydrology and glaciology; she conducted filed research in the Caucasus (Djankuat glacier), the Eastern Sayan Mountains, and the Scandinavian Alps (Tarfala Valley ,Sweden).

Tokarev Igor, PhD. in geology, Senior Researcher of Resource Center "Geomodel", Research Park of Saint-Petersburg State University (Saint-Petersburg, Russian Federation). Specialist in the isotope hydrology and hydrogeology, using δ2H, δ18O, 3H, δ13C, and δ15N environmental tracers, and 3H/3He, U/4He, and 14C groundwater dating. His main scientific interests are associated with climate variations and anthropogenic impact on groundwater and aquatic system. He has practical experience in water management and groundwater flow and mass-transport investigation. He studied water balance and water quality formation, e.g., estimation of the potable groundwater resource in province Almeria (Spain), the Naryn river balance in Kyrgyzstan (Central Asia), and in several regions of Russia. He also studied the clay formations for the underground radioactive wastes repository construction.

Vasil'chuk Yurij, DSc in Geology and Mineralogy, Professor of the Department of Landscape Geochemistry and Soil Geography of the Lomonosov Moscow State University. He has held professor positions at the Cryolithology and Glaciology Department of the Moscow State University in 1996, and was appointed to the positions of Full Professor at the Department of Landscape Geochemistry and Soil Geography in 2009 and Head of the mass-spectrometry laboratory. His research interests are associated with the use of stable and radioactive isotopes in ice wedge, massive ice, palsa, lithalsa, pingo, glaciers, and meromictic lakes research, as well as in isotope studies of soils and landscapes and the origin of hydrological processes in mountainous areas. He was elected to the Russian Academy of Natural Sciences in 2004. He is the author of three university-level textbooks and 15 monographs.

Peter Litinsky
Senior scientist, Forest Research Institute, Karelian Research Centre of RAS, 11 Pushkinskaya St., 185910 Petrozavodsk, Karelia, Russia,
e-mail: litinsky@sampo.ru

STRUCTURE AND DYNAMICS OF BOREAL ECOSYSTEMS: ANOTHER APPROACH TO LANDSAT IMAGERY CLASSIFICATION

ABSTRACT. An alternative approach to information extraction from Landsat TM/ETM+ imagery is proposed. It involves transformation the image space into visible 3D form and comparing location in this space the segments of the ecosystem types with expressed graphically typology of forest and mire cover (biogeocenotic scheme). The model is built in LC1-LC2-MSI axis (the two first principal components of the image matrix in logarithmic form and moisture stress index). Comparing to Tasseled Cap, this transformation is more suitable for study area (north taiga zone of Eastern Fennoscandia). The spectral segments of mature and old-growth forests line up from the ecological optimum (moraine hills) along two main environmental gradients: i) lack of water and nutrition (fluvioglacial sands bedrock) and ii) degree of paludication (lacustrine plains). Thus, the biogeocenotic complexes are identified. The succession trajectories of forest regeneration through spectral space are also associated with the type of Quaternary deposits. For mire ecosystems spectral classes accurately reflect the type of water and mineral nutrition (ombrotrophic or mesotrophic). Spectral space model created using measured by the scanner physical ecosystem characteristics can be the base for developing objective classification of boreal ecosystems, where one of the most significant clustering criterions is the position in the spectral space.

KEY WORDS: boreal ecosystems, geoinformation modeling, multispectral imagery classification, Quaternary deposits

CITATION: Peter Litinsky (2017) Structure and dynamics of boreal ecosystems: Another approach to landsat imagery classification. Geography, Environment, Sustainability (GES Journal), Vol.10, No 3, p. 20-30
DOI-10.24057/2071-9388-2017-10-3-20-30

INTRODUCTION

At present, forest cover mapping is moving from regional to international levels. Data sets from the various countries differ greatly, and development of unified methods is required (Tomppo and Czaplewski 2002; Pekkarinen et al. 2009). The basic data source (Landsat imagery) is used worldwide; thus, it is possible to use the scanner as a tool for unification. The main approach to extracting information from imagery, i.e., supervised classification, is also universal. It is based on the extrapolation of ground truth data to the entire image. Training sites are set according to a previously developed classification scheme which reflects a researcher's understanding about vegetation typology. It depends on the tasks that should be solved (ecology, forestry, geobotany, etc). However, on the one hand, the vegetation is the holistic environmental system with intrinsic laws of functioning; on the other hand, the scanner is a technical device with its own "vision." Therefore, the complete correspondence between the classification scheme and the image information cannot be achieved.

The maximum likelihood classifier (MLC) is thought to be one of the most accurate methods of supervised classification. It has been widely used in forest mapping since the emergence of the multispectral imagery (Hirata and Takahashi 2011). MLC is based on probability and requires normal distribution in each band of ground data, which can be achieved with a large number of training sites. Artificial neural networks (ANN) are also the commonly applied algorithm for the classification of remotely sensed data (Kanellopoulos and Wilkinson 1997; Zhou and Yang 2008). Their application also requires a careful selection of training sites. However, any number of plots is useless if the classification scheme poorly conforms to the capabilities of the scanner for categories recognition. Thus, these methods of information extraction can hardly be used as the base for data sets unification. Uncertainty at the regional level is carried to the global.

The process of image classification using techniques such as MLC and especially ANN, is almost a "black box." The researcher cannot estimate the real size and location of the categories in spectral space, their relative spatial position, i.e., actually acts blindly. Commonly used bi-band scatterplots (feature space images) are only a partial solution to the problem. Long term studies of the taiga landscapes structure and dynamics using remote sensing data (Litinsky 1997, 2007) suggested that the natural space structure of ecosystems can be much better revealed using another approach, which can be named "spectral space modeling" (Litinsky 2011, 2012). It includes three key components: i) creation of graphical expression of forest and mire cover typology (biogeocenotic scheme); ii) transformation of image spectral space into a visible 3D form, and iii) comparison of the positions of the ecosystem signatures in spectral space with the biogecenotic scheme. An example of this approach is briefly described below.

MATERIALS AND METHODS

Study area

The area encompasses about 10 million ha in north taiga of Eastern Fennoscandia (Fig. 1). The altitude ranges from 0 to 350 m a.s.l., mean annual temperature is about 0ºC, long-term mean annual precipitation is 500-550 mm. The area is a sample of continental glaciation. The Quaternary cover is formed by the glacial (moraine) and fluvioglacial (delta, sandur) deposits that cover Precambrian bedrock of the Fennoscandian Shield. They are locally overlain by lacustrine and marine sand-clay material and peat deposits. The

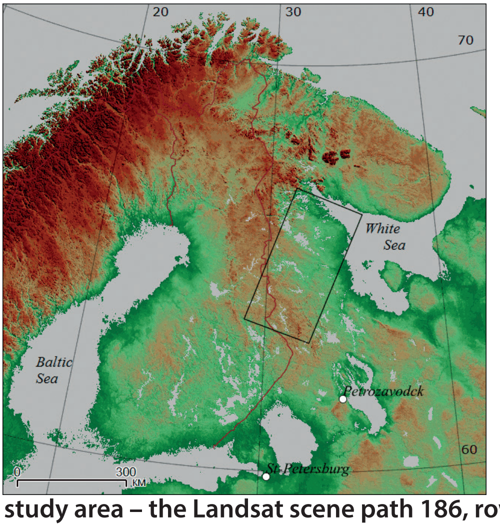


Fig. 1. The study area – the Landsat scene path 186, rows 13-15

exposures of ancient crystalline rocks are very common in denudation-tectonic relief prevailing here. The lake surface/drainage area ratio is remarkably high, 12% (Biotic diversity... 2003).

The area includes all main north taiga ecosystem types. There are three forest forming species here: Scots pine (Pinus silvestris L.), Finnish spruce (Picea x fennica (Regel) Kom.), and white birch (Betula pubescens Ehrh.). Due to intensive cuttings since the early 1960s, more than two-thirds of forests are currently younger than 50-60 years. The large fragments of old growth forests have remained only along the Finnish-Russian border.

More than 80% of the forest land is covered with pine forests that occur in almost all types of habitats, formed on different Quaternary deposits (Volkov et al, 1995). Their diversity can be represented in the axes of the edaphic coordinates diverging from the ecological optimum (Fig. 2). Spruce-dominated stands (12% of the forest land) occur mostly on the slopes of moraine hills and wet depressions. Birch is an accompanying species in stand composition.

Due to excessive moistening and little evaporation, open mires occupy about one-third of the area. The largest mire systems are located on sea and lacustrine plains. Significant parts of forests are the ecotones between open mires and terrestrial ecosystems. The area is sparsely populated, with only one industrial center there – Kostomuksha ore-dressing mill. Agricultural lands (mostly meadows) occupy about 1.5%.

Image Data and processing

Landsat ETM+ images from path 186 rows 13-14 acquired 2000.07.28 and row 15 (2002.06.16) were used for model creation. Landsat TM images from the same path, row 14 (1992.06.12) and row 15 (1990.06.23) were taken as time series, all obtained at ftp://ftp.glcf.umiacs.umd.edu.

The spectral space model is built in LC1-LC2-MSI axis: the two first principal components

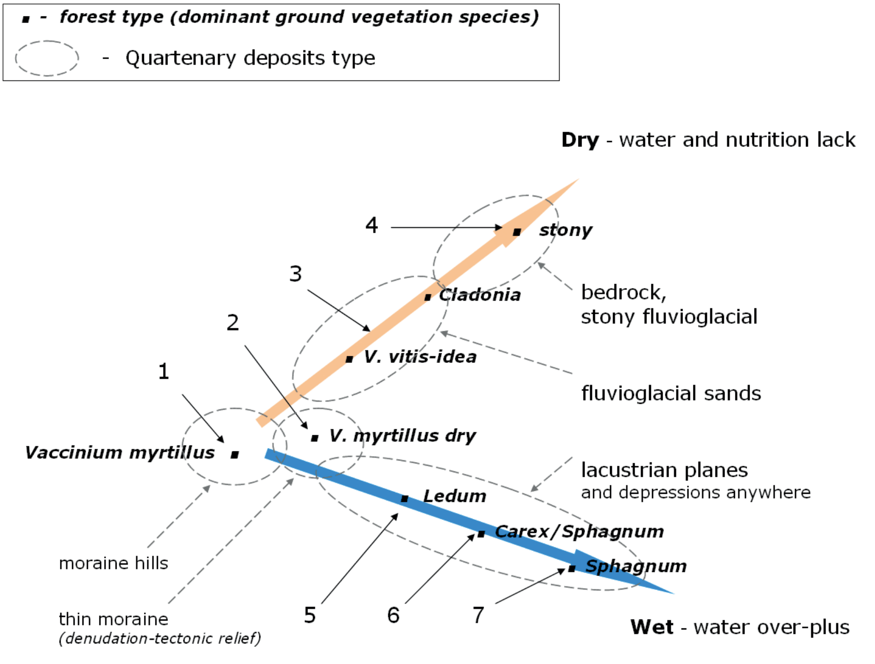


Fig. 2. The biogeocenotic scheme of north taiga pine forests. "Dry" and "Wet" are the automorphic and hydromorphic axes, respectively. Digits 1–7 are the reference points for comparison with the spectral space model shown in Fig. 4.

of the image matrix in logarithmic form, and Moisture Stress Index. LC1 accounts for general scene brightness, LC2 correlates with quantity of green biomass, but not orthogonal to brightness (Litinsky, 2011). Thus, in physical terms this transformation is the gnuplot plotting utility was used for 3D visualization and analyzing the spectral space model. Localization of spectral classes within the model space was made using aerial images, forest inventory maps, landscape transects, and other ground data.

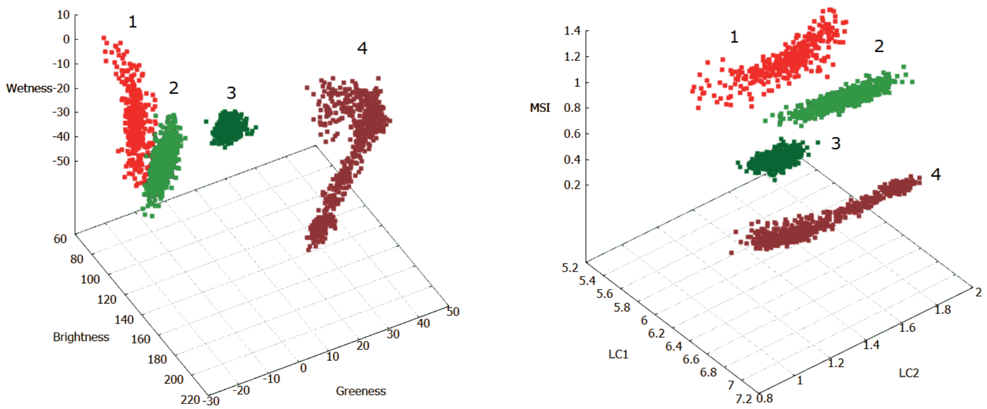


Fig. 3. Signature clouds of the same mire (1 and 4) and forest (2 and 3) plots in Tasseled Cap (left) and LC1-LC2-MSI space.

similar to Tasseled Cap (Kauth and Thomas, 1976; Huang et al, 2002), but it makes space more "compact", understandable, and suitable for analyzing (Fig. 3).

The lightest categories (cuttings, mires) are represented significantly in spectral space not due to their heterogeneity, but only to the largest value of albedo. The logarithm equalizes the values of the dark forest and bright non-forest categories, with open water zone being scattered. MSI is opposite to "wetness" and it makes space visually closer to human perception: dry and poor vegetation is at the hill top, rich and wet in the valley. Three minimally mutually correlating bands were used for the axes LC calculation:

$LC1 = 0.2793 \times \ln(R) + 0.7786 \times \ln(NIR) + 0.5619 \times \ln(SWIR2)$;
$LC2 = 0.5887 \times \ln(R) - 0.6012 \times \ln(NIR) + 0.5404 \times \ln(SWIR2)$;
$MSI = SWIR1/NIR$;

where R, NIR, SWIR1, SWIR2 - Landsat ETM+ bands 3, 4, 5, 7 digital numbers, respectively; ln - natural logarithm.

Free RS/GIS packages QGIS, SAGA, and GRASS, were used for image processing;

RESULTS

Any of more or less homogeneous category of an ecosystem (e.g., even-aged stand forest canopy or meadow surface) is represented in the model as a lenticular object (oblate ellipsoid) tilted to the plane of LC1-LC2, e.g., cloud 3 in Fig. 3 ("oblate" means that variation in the MSI value is significantly less than in LC1 and LC2). For illustration purposes only, the centers of classes forming "molecule" ball-and-stick segments are shown. The most essential features of the 3D model are shown below step by step: a) mature and old growth forests: b) pine forest regeneration after cutting; c) open mires, and d) destroyed categories, starting with forest ecosystems located in the central, "core" part of spectral space. These categories include the vast majority of vegetation types of the territory, more than 95% of the area.

Mature and old growth forests

The biogeocenotic scheme shown in Fig. 2 is an "imaginary" construction, based on ground observations, while the spectral space model is real, albeit virtual. Nevertheless, the location of reference points 1-7 in Fig. 2 almost completely coincides with the position of the mature and old-growth pine forest classes in spectral space (Fig. 4).

Both gradient lines, dry and wet, go along axis LC1 from dark to bright parts of spectral space due to reduction of radiation absorption by canopy caused by decreasing leaf area index (LAI), which, in turn, is a result of edaphic conditions deterioration. Besides, along the dry gradient the moisture stress grows, and line goes up. There is no moisture lack along the wet gradient, and the line remains almost horizontal. Due to their wide ecological amplitude, pine stands occupy all the forest zone of spectral space. Class 1 is the most productive mixed pine-spruce-birch forest with spruce undergrowth. Dominant ground vegetation species are Vaccinium myrtillus and V. vitis-idaea; the soils are Ferric and Ferric-Carbic Podzol. Class 3 is pure pine stands on fluvioglacial sands, with pine undergrowth, the soil is sandy shallow Podzol. Wet concave spots are of the V. vitis-idaea type, while dry convex ones are of the Cladonia type. Class 4 represents low productive pine stands growing on bedrock or boulder fluvioglacial sediments with primitive soils (Leptosol). The ecosystems located along the wet gradient line are the ecotones between automorphic habitats and open mires. Class 5 is formed by mixed pine-birch-spruce stands at an intermediate stage of paludifcation with a thin peat layer (up to 0.3-0.5 m); the ground vegetation is a dwarf shrubs (Ledum palustre, Vaccinium uliginosum). Classes 6 and 7 are pure sparse pine stands of Sphagnum and Carex-Sphagnum type, respectively.

Classes 5 and 6 occupy large areas at the periphery of mesotrophic mires; class 7 is commonly a narrow strip alone the edge of ombrotrophic mires. The strip width is often less than 30 m, so the scanner is unable to register it. Thus, in most cases, the location of pine forests in spectral space coincides with their location in the axis of edaphic and phytocenotic coordinates, and the biogeocenotic complexes (quaternary deposits + vegetation) can be identified. Obviously, the scanner registers not the type of Quaternary sediments as such, but the conditions of water and mineral nutrition, most typical for specific type of habitats.

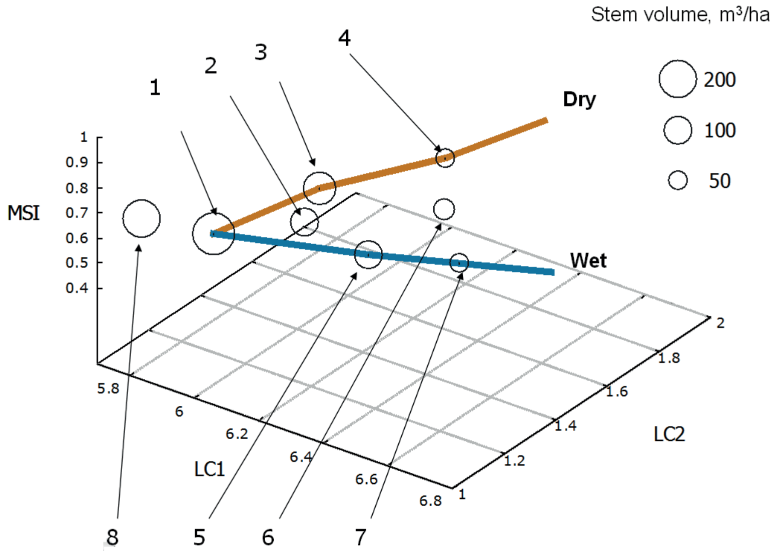


Fig. 4. A spectral segment of mature forests. Points 1–7 are the same forest classes as in Fig. 2. Class 8 is closed canopy spruce stands. Mean stem volumes are calculated from forest inventory data.

Class 2 is relatively ambiguous; it can be marked as the "open canopy conifer stands." Due to pixel size 30x30 m, the scanner registers mixed signal from crowns, ground vegetation, and tree shadows, which makes it impossible to determine the tree species composition, and even dominant species. In some cases, this is possible by using the landscape context; e.g., in denudation-tectonic relief, this class includes pine-dominated, or pine-spruce stands of the dry myrtillus type, while on abraded, smoothed drumlins of sea plane (the White Sea lowland) one can find spruce stands of the wet myrtillus type. If a sufficiently detailed digital elevation model (DEM) existed, then the discrimination of these classes could have been made with the use of some geomorphometric indexes (Wood 1996). Thus, the two types of habitats above have rather different values of fractal dimension. It should be noted that these classes are rather similar types of vegetation in terms of the mass and energy exchange (without account of tree species composition).

Class 8 is represented by spruce-dominated stands with closed canopy growing on the slopes of moraine hills (myrtillus type), and more wet variants (Sphagnum/myrtillus) occupying gentle slopes at the foot of hills and depressions. Stands of this type have high LAI; most solar energy is absorbed, making them difficult targets for discrimination of classes (Cohen et al 1995). Thus, class 2 is ambiguous due to low canopy density, while class 8 – owing to high density. In both cases discrimination is possible using DEM.

A more or less significant proportion of spruce in stand composition is observed in classes 1, 2, and 5, closest to the optimal edaphic condition. In these classes, the share of birch may reach 20-30%. All forest classes have a few parts with different canopy density, so the total number of mature forest categories exceeds 20.

Pine regeneration

The cutting in this territory is carried out in the most productive habitats (classes 1 and 3 in Fig. 4). The locations of new clearcut class is almost the same for both habitats, but the succession trajectories of forest regeneration through spectral space are sharply different depending on the type of Quaternary deposits (Fig. 5).

The exact position of the trajectory end point (pine or spruce domination), as well as succession velocity, especially at last stages, depends on local conditions: landscape context, details of edaphic features, and the

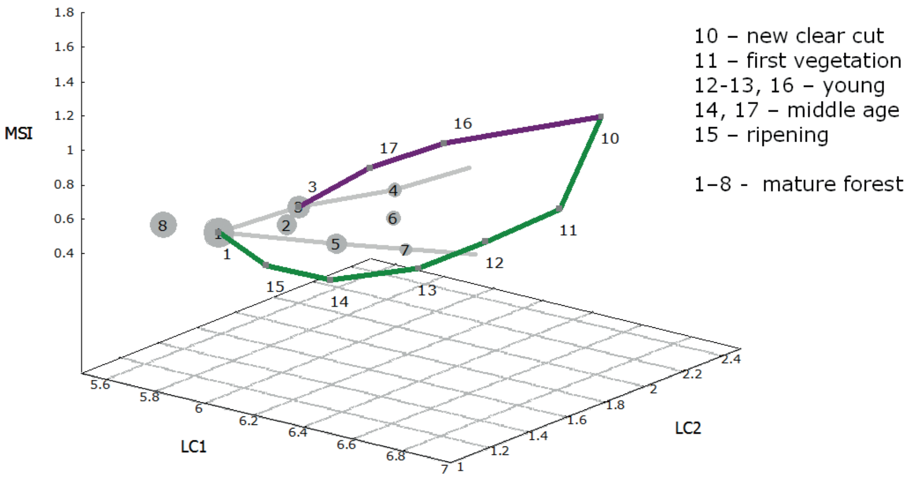


Fig. 5. Trajectories of pine forest regeneration on moraine (green) and on fluvioglacial deposits (purple). Light grey is mature forest segment (classes 1-8).

availability of spruce and/or pine seeds. On fluvioglacial sands, the trajectory is almost a straight line, age stages are less visible than on the moraine. Multi-temporal images are required for better discrimination.

Open mires in this territory are presented by two main types of water-mineral nutrition: ombrotrophic (oligotrophic) and mesotrophic. These mires have significantly different microrelief and vegetation cover; dominant species are Sphagnum and Carex, respectively. Due to differences in reflectance, in spectral space mires encircle the forest zone from opposite sides (Fig. 6). Different types of mires form wide "blades" of complex shape; only the main centerlines are shown here. Position in spectral space also reflects the level of water table, from inner lakes and pools in the dark part of space to the dried plots occupying the brightest part.

Deeply transformed ecosystems (shrubs, meadows, crops) are located in the right, lightest part of space (Fig. 7). The trajectory of forest recovery after the fire moves from the dark side in the direction of a new clearcut. Non-vegetation categories, such as sands and ore careers, roads and settlements, occupy the zone with the maximum MSI value.

Ecosystem map

The simplest way to transform the spectral space model into the map is to use LC1-LC2-MSI coordinates of the points in Figures 4–7 as class centers for the minimum distance classification. Obviously, this method is rather illustrative. For more accurate modeling of the space structure and further mapping, the full voxelization is required. This is especially the case for complex mire systems and forest-mire ecotones. The vectorized classification result is shown in Fig. 7. Two-step generalization was applied: "mode" filtering to the classified raster and the cleaning topology tool "remove small areas" after vectorization.

The position in spectral space defines a type of the biogeocenoic complex (Quaternary deposits/vegetation), which, in turn, determines the soil type, biological productivity, tree species composition, undergrowth, and ground vegetation, i.e., qualitative, intrinsic biogeocenotic characteristics. Specific quantitative values of such parameters as stem volume, average height, dbh, etc., can be calculated using forest inventory data. These values compose the attribute data of the vector layer. So, the ecosystem model can produce a set of thematic maps: land use categories, Quaternary deposits, forest inventory, soil and mire types, biological productivity, anthropogenic disturbance, etc.

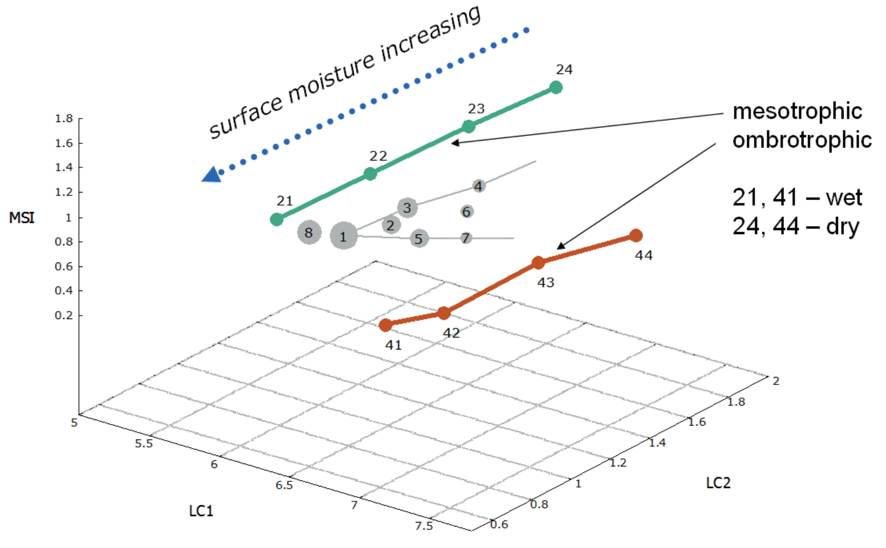


Fig. 6. Segments of open mires.

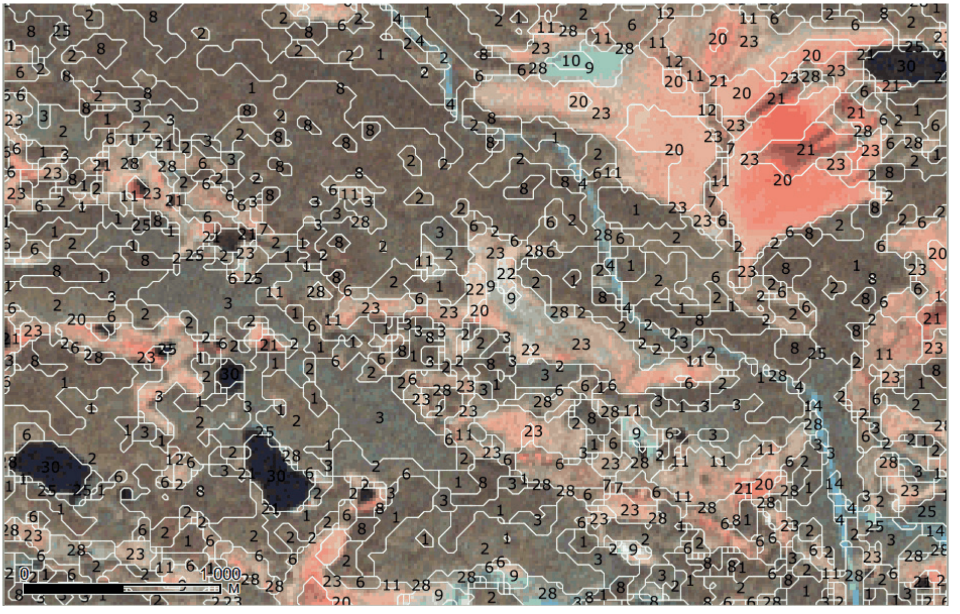


Fig. 7. A fragment of the vector layer of vegetation model. Background RGB-synthesis of infrared channels (4-5-7). Coordinates of the center 64.4752 N, 30.6894 E

DISCUSSION

Figures 4–6 show that spectral space of the scanner image is a complicated system of zones and trajectories. However, it can be easily interpreted in ecological terms. The investigation of these patterns to create a vegetation map is thought to be much more reasonable, effective, and interesting than "blind" supervised classification. The process starts with the biogeocenotic scheme creation (Fig. 2) by studying published materials on Quaternary deposits and vegetation typology of the study area. At this stage, the visible scanner image of the area is created (RGB-synthesis from infrared channels). As a result of the analysis of all the data available, the first variant of the classification scheme is obtained. The next step is to build the spectral space model. Protected areas are believed to be ideal as reference objects: their ecosystems are undisturbed (this facilitates the localization of spectral classes) and usually well studied and mapped. The procedure of taking training sites signatures is conventional.

After preliminary localization of the main ecosystem classes in spectral space and its visualization with the gnuplot utility, the model refinement begins and the advantages of 3D modeling become apparent. The capability to examine the whole spectral space from any side, as well as the location and relative position of different categories are fundamentally important as it involves human intuition into analysis. Two bi-dimensional scatterplots Brightness/Greenness and Brightness/Wetness (e.g. Cohen et al 1995; Krankina et al 2008) are much less informative.

The spectral space model makes it possible to purposefully correct the position of class centers in space by editing the statistical table for the minimum distance classification and to find optimal classification variant by the trial-and-error method. The supervised classification is one-directional, i.e., it goes from training sites to the entire image. In 3D space, interpolation becomes possible. It is logical to assume that the categories with intermediate characteristics can be found in the space span between classes with known properties. To test this hypothesis we can simply add a new line with space coordinates into the statistical table. We can also determine where the category occupying a specific part (LC1-LC2-MSI) of spectral space is located in the map. And, most importantly, there is the possibility to see the classification results both in geographical and spectral space, e.g., as a set of voxels, or points clouds. To conclude, the classification can be transformed from supervised to manageable one, thus allowing to extract a greater amount of information from the image.

These new opportunities improve our understanding of the way the scanner recognizes different types of vegetation, and provide a much more effective feedback mechanism of training sites selection, as compared to the accuracy assessment by the kappa statistics. In some cases, classes discrimination by non-visual methods is practically impossible, but is very simple in visible 3D space. This can be applied to forest edges at the borders with mires and lakes, as well as to any types of narrow ecotones. Preliminary results have shown that the proportion of such categories is remarkably high.

The spectral space model is a link between technical image information and human understanding of ecosystems typology. It plays the role of interactive, mobile classification scheme. Creating the spectral space model is a long-term research process. As a result, the first detailed digital map of the biogeocenotic structure for the study area has been compiled. The model includes all basic classes of primary ecosystems, and some variants and stages of their natural and anthropogenic disturbances. The number of detail is constantly increasing. Accuracy assessment was carried out by comparing with the georeferenced database "CORINE-biotopes" (Söderman 1997). Taking into account the level of generalization, the degree of identity was almost 100% (Kryshen and Litinsky 2013). Such accuracy is quite explicable. Plants and environment are interacting as a physico-chemical system (Pignatti et al 2002). The scanner registers the physical characteristics of biogeocenosis. This allows allocating a relatively small number of generalized ecosystem classes with an almost absolute certainty.

The biophysical base of such a classification makes it independent of local (forestry, geobotanical) typologies and, thus, provides an opportunity for creating an internally consistent vegetation map for large areas. It should be noted that currently the main barrier to increase the map detail is the lack of high resolution DEM. The ideal variant would be the use of LiDAR data, which would also allow receiving the information on canopy architecture. Decomposition of the spectral classes by these parameters could increase the total number of recognized classes of vegetation several times.

CONCLUSIONS

The spectral space model reflects the continual structure and dynamics of vegetation cover in space and time in a clearly visible form. The model analysis substantially facilitates the classification process and allows extracting much more information from the image that was previously unavailable. Maps derived from spectral space models can be useful for forest management and the monitoring of landscape mosaic dynamics on the regional level and will help investigate landscape structure with quantitative methods. However, its mission seems to be more fundamental. Perhaps, the spectral space model can serve as the foundation for objective classification of ecosystems, where one of the most significant clustering criteria is the mathematically expressed position in spectral space. Practically, it will help reduce uncertainty in forest mapping at the global level. An internally consistent ecosystem map can be a spatial frame for integration of discrete fragmentary data (phytocenotic, geobotanical, landscape ecological) into the holistic space-time continuum, i.e., a comprehensive structural and functional model.

Preliminary analysis has shown that spectral models are rather similar in TM/ETM+ images of Fennoscandia, Siberia and Canada. Free web-enabled imagery and software are used for the approach implementation, so it could be applied right now. In our opinion, it is likely to be of interest to the unconventionally minded researchers and students. It would be beneficial to test this approach in similar natural conditions and in other boreal territories.

REFERENCES

Biotic diversity of Karelia: conditions of formation, communities and species (2003). Petrozavodsk: Karelian Research Centre of RAS.

Cohen, W. , Spies,T. and Fiorella M. (1995). Estimating the age and structure of forests in a multi-ownership landscape of western Oregon. U.S.A. Int. J. Remote Sensing, Vol. 16 No 4, pp. 721-746.

Hirata, Y. and Takahashi, T. (2011) Image segmentation and classification of Landsat Thematic Mapper data using a sampling approach for forest cover assessment. Can. J. For. Res. 41(1): pp. 35-43. doi:10.1139/X10-130

Huang, C.; Yang, Wylie L.; Homer, Collin and Zylstra, G. (2002). Derivation of a tasseled cap transformation based on Landsat 7 at-satellite reflectance: USGS Staff -- Published Research. Paper 621. http://digitalcommons.unl.edu/usgsstaffpub/6

Kanellopoulos, I., Wilkinson, G.G., (1997). Strategies and best practice for neural network image classification. International Journal of Remote Sensing, 18(4), pp. 711-725.

Kauth, R . and Thomas. G. (1976) The Tasseled Cap a graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. In: Proceedings on the Symposium on Machine Processing of Remotely Sensed Data, 4b: 41-51, 6 June 2 July 1976 (West Lafayette, Indiana: LARS, Purdue University).

Krankina, O. , Pflugmacher, D., Friedl, M., Cohen, W. B., Nelson, P., and Bacini, A. (2008) Meeting the challenge of mapping peatlands with remotely sensed data. Biogeosciences Discuss., 5, 2075-2101, doi:10.5194/bgd-5-2075-2008.

Kryshen A., Litinsky P. (2013) Sopostavleniye i vzaimnaya verifikatsiya geoinformatsionnoy i ekologo-dinamicheskoy modeley raznoobraziya lesnykh ekosistem [Comparison and mutual verification of the geoinformation and the ecological dynamics models of forest ecosystems diversity]. Trudy KarNTS RAN. № 2, pp. 86-91. (in Russian)

Litinsky P. (1997) Assessment of forest decline around Kostomuksha ore-dressing mill using satellite images In: Ecosystems, fauna and flora of the Finnish-Russian Nature Reserve Friendship. Finnish Environment Institute, Helsinki, pp. 341-346.

Litinsky P. (2007) Trekhmernoye modelirovaniye struktury i dinamiki tayezhnykh landshaftov [3D modeling of taiga landscapes structure and dynamics] Petrozavodsk: KarNTS RAN. 130 p. (in Russian)

Litinsky P. (2011) Klassifikatsiya skanernykh snimkov metodom modelirovaniya spektral'nogo prostranstva [Multispectral imagery classification method based on spectral space modeling]. Trudy KarNTS RAN RAN, № 5, pp. 45-54. (in Russian)

Litinsky P. (2012) Geoinformatsionnaya model' nazemnykh ekosistem severotayezhnoy podzony vostochnoy Fennoskandii [Geoinformation model of Eastern Fennoscandia northern taiga ecosystems]. Trudy KarNTS RAN. № 1, pp. 3-15. (in Russian)

Pekkarinen, A., Reithmaier, L., and Strobl, P. (2009). Pan-European forest/nonforest mapping with Landsat ETM+ and CORINE Land Cover 2000 data. ISPRS J. Photogramm. Remote Sens. 64(2): 171183.

Pignatti S., Box E. , Fujiwara K. (2002). A new paradigm for the XXIth century // Ann. Bot. Vol. 2. P. 3057.

Söderman T. (1997). Biotopes Mapping of the Eastern Baltic. CORINE Biotopes 17 Project in the Baltic States and Northwestern Russia. Nord, 100 p.

Tomppo, E., and Czaplewski, R.L. (2002). Potential for a remotesensing-aided forest resource survey for the whole globe. Unasylva, 210: 1618.

Volkov A. , Gromtzev A. , Erukov G. et al. (1995) Ekosistemy landshaftov zapada severnoy taygi (struktura, dinamika) [Ecosystems of north-west taiga landscapes (structure, dynamics)]. Petrozavodsk, KarRC RAS, 194 p. (in Russian)

Wood, J. (1996). The Geomorphological characterisation of Digital Elevation Models. Diss., Department of Geography, University of Leicester, U. K. http://www.soi.city.ac.uk/˜jwo/phd

Zhou, L. and Yang, X. (2008). Use of neural networks for land cover classification from remotely sensed imagery, The International Archives of the Photogrammetry. Remote Sensing and Spatial Information Sciences, vol. XXXVII, part B7, Beijing, pp. 575-578.

Received on September 06th, 2015 Accepted on August 10th, 2017

Peter Litinsky graduated from the Leningrad Forest Academy and obtained his PhD degree from the St.-Petersburg Institute of Forestry in 1997. Since 2003, he is Senior Scientist of the Forest Research Institute of the Karelian Research Centre, RAS. The focus of his research is on remote sensing and GIS aided modeling of the structure and dynamics of taiga ecosystems.

Philipp Thumser[1], Vyacheslav V. Kuzovlev[2], Kyrill Y. Zhenikov[2], Yuri N. Zhenikov[2], Max Boschi[3], Peter Boschi[3], Martin Schletterer[4]
[1]P. Thumser, I AM HYDRO GmbH - Investigation and Monitoring of Hydrosystems, iamhydro.com, Märtishofweg 2, 78112 St. Georgen, Germany
[2]V.V. Kuzovlev, K.Y. Zhenikov • Y.N. Zhenikov
Tver State Technical University, Chair of Nature Management and Ecology
nab. Afanasiya Nikitina 22, 170026 Tver, Russia
[3]M. Boschi, P. Boschi
droneproject.at, Schneeburggasse 225, 6020 Innsbruck, Austria
[4]M. Schletterer (*) University of Innsbruck, Institute of Ecology
Technikerstrasse 25, 6020 Innsbruck, Austria e-mail: martin@schletterer.co.at

USING STRUCTURE FROM MOTION (SFM) TECHNIQUE FOR THE CHARACTERISATION OF RIVERINE SYSTEMS - CASE STUDY IN THE HEADWATERS OF THE VOLGA RIVER

ABSTRACT. Digital terrain models (DTM) were produced with the structure from motion (SfM) technique, using data from high resolution terrestrial photography. In addition 360-degree spheres were created from ground taken photos. These spheres allow capturing the environment at this moment and coming back to the environment virtually later on. Also overlapping this virtual realty of the environment with model results can be used for distributing study results to a broad audience. On this basis hydraulic and morphological conditions were assessed and compared to field records. The proposed methods enable the creation of a detailed view on different riverine systems, i.e. from small to large rivers. This enables a morphodynamic characterisation which can be linked with the biological dataset of the monitoring project REFCOND_VOLGA. We propose that environmental intelligence gathering using ground-based as well as remote sensing observations can be applied increase the scope of scientific surveillance, and can lead to new opportunities to detect and quantify complex ecological interactions across a wide spectrum of scales.

KEY WORDS: photography, photogrammetry, 360° panorama, environmental intelligence

CITATION: Philipp THUMSER, Vyacheslav V. KUZOVLEV, Kyrill Y. ZHENIKOV, Yuri N. ZHENIKOV, Max BOSCHI, Peter BOSCHI, Martin SCHLETTERER (2017) Using structure from motion (SFM) technique for the characterisation of riverine systems - case study in the headwaters of the volga river. Geography, Environment, Sustainability (GES Journal), Vol.10, No 3, p. 31-43
DOI-10.24057/2071-9388-2017-10-3-31-43

INTRODUCTION

A wide range of applications and benefits of this novel image-based remote sensing technology is already shown (Everaerts 2008; Remondino et al. 2011; Nex and Remondino 2013; Whitehead et al. 2014), mostly taking the sensors up in the air with a Unmanned Aerial Vehicle (UAV), but surveys are basically also possible from the ground. Systems with advanced measurement equipment have become smaller, safer, and more efficient, due to advances in materials, electronics and software. A common application is the generation of high-resolution geo data, with a relatively small expenditure of time. Besides interesting new perspectives on nature, the most promising advantages of this new technology are a decrease in time and effort for surveying as well as an increase of safety and accuracy.

For claiming a fast method, a new approach was derived from photogrammetric analyzes of satellite and aerial imagery: the Structure from Motion (SfM) (Fig. 1) method (Snavely et al. 2006, 2007). Both photogrammetric and SfM generated geo data and their accuracy have been proofed over the last decades, now both on large scale and small scale (Eisenbeiss and Zhang 2006; Mancini et al. 2013; Hugenholtz et al. 2013; Smith and Vericat 2015; Smith et al. 2015). Related to progress in software development and increases in computer performance, the generation of digital elevation models (DEM) and orthomosaics imagery using SfM is becoming increasingly common.

Therefore the application of this technology within the field of hydro sciences and engineering is a promising tool, especially for modeling purposes. Hydraulic models are used and developed commonly, to study a variety of hydrogeomorphic processes as well as to design river rehabilitation projects. Advances in hardware and model coding bring model application and performance to new levels (Barker et al. 2010). Boundary conditions for hydraulic models as well as changes from erosion and deposition of sediments can be tracked through transect measurements over long periods (Klein et al. 2007). Natural and near-natural rivers often feature a large variety of morphological characteristics, which cannot be measured simply as a series of two-dimensional transects (Buffington and Montgomery 2013). This leads to the necessity of increasing advances in data ascertainment, especially in topographic mapping, to provide data for driving these large and detailed simulations. For larger scale this can be performed with Aerial Photogrammetry (Dietrich 2015) and Airborne Laser Scanning (ALS) (Charlton et al. 2003). But they are also limited by equipment costs, which can become critical considerations for smaller projects or if surveying has to be conducted regularly with these methods. UAV can be one solution for this situation, but depending

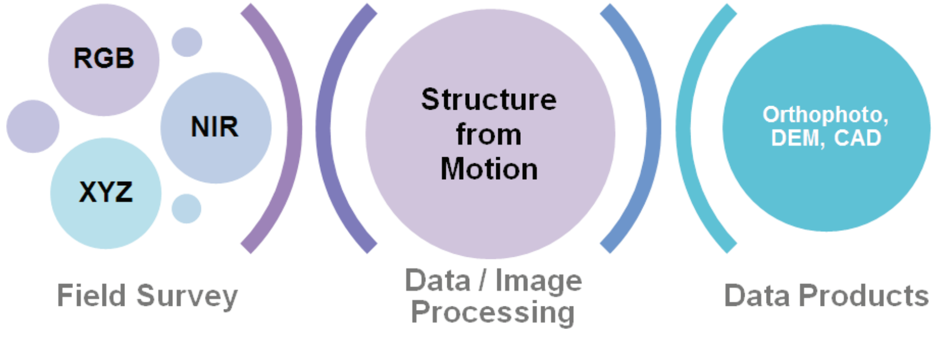


Fig.1. The structure from motion (SfM) technique increases scope and accuracy of river surveys.

on regulations also UAV flights might not be possible, especially when date and time for the field survey are fixed very shortly before starting. Also for practical reasons other solutions can be easier to conduct compared to ground based survey, e.g. for very remote places with re-charging opportunities.

Overall image (photo) based surveys and post-processing with SfM can provide reliable data with a very high accuracy an appropriate amount of time and with the added advantage of easy and fast replication and repetition (Fonstad et al. 2013). This data combinded with appropriate post-processing can be used for mapping topography in river environment (Room and Ahmad 2014; Thumser et al. 2015), mapping river bathymetry (Flener et al. 2013; Javernick et al. 2014; Ouédraogo et al. 2014; Bagheri et al. 2015; A. Tamminga et al. 2015; Woodget et al. 2015), mapping vegetation (Berni et al. 2009; Mathews and Jensen 2013; Flynn and Chapra 2014; Kaneko and Seiich Nohara 2014), mapping and quantifying sediment and habitat parameters (Casado et al. 2015; Woodget 2015), quantifying changes in morphology, erosion and deposition (Wheaton et al. 2010; Lucieer et al. 2013; Smith and Vericat 2015; Tamminga et al. 2015; Stumpf et al., 2015) and many more. The particular value of the monitoring data lies in the combination of a high spatial and a moderate temporal resolution (Hering et al. 2010). Data acquisition and surface water mapping of aquatic habitats is critical to assess the conditions of lentic ecosystems as well as for planning. This approach demands intensive cooperation of engineers, ecologists and geomorphologists to determine the essential characteristics with sufficient accuracy (Rice et al. 2010).

This article describes the methodology and it`s application within the monitoring programme REFCOND_VOLGA, in the headwaters of the Volga.

RESEARCH AREA

Within the research expedition "Upper Volga 2005" an assessment of hydrological, hydrochemical and biological parameters was carried out in the Volga River upstream of Tver, including the main channel as well as major tributaries. This assessment revealed that the headwaters of the Volga River represent conditions which are either reference or least disturbed and stipulated the establishment of the monitoring programme "REFCOND_VOLGA", which is in operation since 2006 and includes stretches along the Volga River (Rzhev, Staritsa, Tver) as well as along the tributary Tudovka. This long-term monitoring includes assessments of hydrochemistry, as aquatic flora / fauna as well as hydromorphology (Schletterer et al. 2016). Therefore a detailed assessment, applying the structure from motion (SfM) technique as well as the establishment of 360°-panoramas, was carried out to supplement the environmental intelligence gathering at the monitoring sites.

MATERIAL & METHODS

Field work

Survey for SfM analyses

A standard camera (Canon EOS 600D) was used for generating the pictures. It uses a 18 Megapixel APS-C CMOS-Sensor with 18mm fixed focal length. Usually a UAV would be used for faster surveying at middle and low height. But as UAV flying is regulated and time consuming (dependence on weather conditions, flight planning), for the current study a ground-based survey was chosen. The photographer stood on one riverbank heading to the other bank in a 90° angle to the stream. Focusing the other bank, each photo should cover around 30% of the water surface and 70% of the bank and the terrain above and behind. This ensures that in the post-processing the software is able to find the water line and that it is covered in the whole model. After each photo is taken, the photographer takes a few steps to the side, focuses again and takes the next photo. The step should be the distance that ensures a total coverage of around 80% or more from photo to photo (Fig. 2). The process was continued until the total area of interest is covered, with a decent extra area in

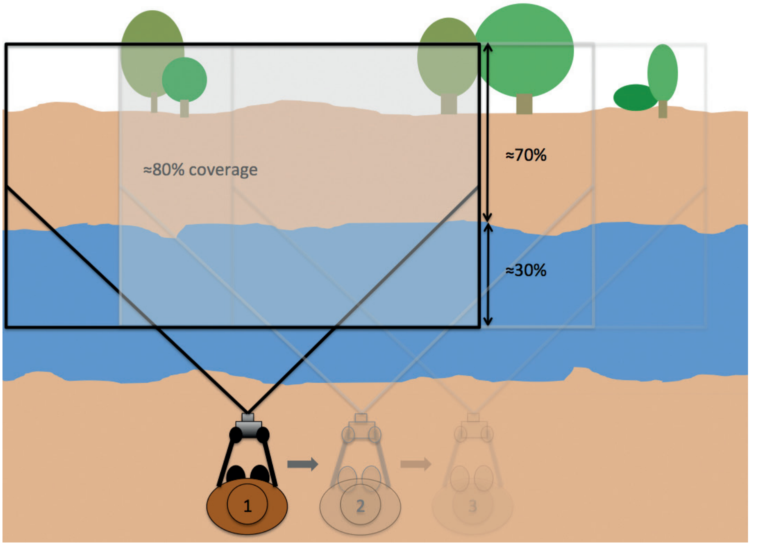


Fig. 2. Schematic drawing of terrestrial photographing of a river for SfM model purpose. The photographer takes one position and shoots a photo (1) and moves on to the next position (2) for shooting another photo with 80% total overlapping and so on (3).

the beginning and at the end (boundary conditions). After finishing one riverbank and screening the quality of the images in the field, the procedure was repeated from the other riverbank. These photos are used for SfM post-processing later on.

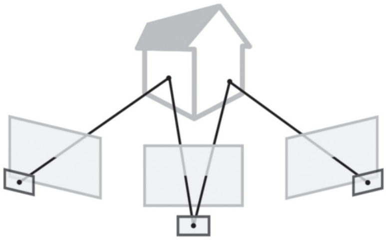
Virtual River (360° panorama)

Creating virtual spheres has certain requirements on the photo technique that are different to SfM requirements. While pictures taken for post-processing with SfM should contain motion, meaning angle and distance to the object of interest and therewith the position of shooting should vary between the captures, photos taken for virtual spheres should be made from one single point. Usually a tripod and a nodal point adapter are used in addition to the camera. The equipment is placed at point, which is identic to the viewers position the virtual tour later on, and the whole surrounding in all dimensions is captured with photos taken from this point without changing camera height and position. This procedure is repeated for different positions. In the post processing this points can be merged together to a tour, where the user can move from point to point. As no nodal point adapter and tripod was available during field trip for logistical reasons, photos were taken by hand, trying not to change position and height during the photos.

POST PROCESSING

SfM for high resolution topographic reconstruction

„Structure-from-Motion“ (SfM) is a photogrammetric method for high resolution topographic reconstruction, which differs fundamentally from conventional photogrammetry as the geometry of the scene, camera positions and orientation is solved automatically (Westoby et al. 2012). The SfM approach uses a highly redundant, iterative bundle adjustment procedure based on a database of features automatically extracted from a set of multiple overlapping images (Snavely et al. 2008). The 3D point cloud generated through the SfM workflow is in a relative „image-space“ coordinate system and has to be transformed to an absolute coordinate system (Fig. 3). Mostly achieved using a 3-D similarity transform based on a small number of known ground control points (GCPs) with known object-space coordinates, it is part of the post-processing after the SfM workflow described below.


(A)

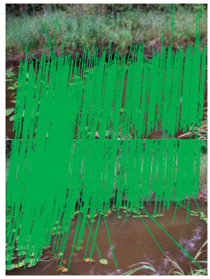

(B)

Fig. 3. (A) The SfM technology relates image coordinates (gained from different camera positions) with world coordinates, this approach is exemplified in (B) which shows the comparison of images in Visual SFM

The SfM workflow presented herein is common for a number of open-source applications, which are implemented e.g. in VisualSFM (Wu 2011) as well as in the application bundle SFMToolkit3 (Astre 2010). VisualSFM is a freely availaible GUI application using structure from motion for 3D reconstruction. This system integrates SiftGPU, a multicore bundle adjustment and for processing of a dense cloud the Clustering View or Multi-view Stereo (CMVS) and Patch-based Multi-view Stereo is implemented (Wu 2007; 2011). The bundle SFMToolkit3 includes SiftGPU (Lowe 2004), Bundler (Snavely et al. 2008), CMVS and PMVS2 (Furukawa and Ponce 2007; Furukawa et al. 2010). The input data are pre-calibrated images which have been undistorted, thus this is a user-friendly procedure to a sparse and dense point cloud, which is the basis for a digital terrain model (DTM) with different resolutions (Fig. 4).

The initial processing step of the SfM workflow is feature extraction on every image in the photoset. There are different methods existing for automated detection of feature points, but most commonly used, the scale-invariant feature transform (SIFT) proved to be very robust against rotation and scaling and is partially invariant to illumination changes and view point variation. After the creation of a feature descriptor, matching of the extracted features is performed between all images. A detailed description of the SIFT algorithm is shown in Lowe (2004). The relative camera orientation between pairs of images is estimated with the established feature correspondences between images. The bundle adjustment system used in Bundler (Snavely et al. 2008) estimates camera pose and reconstructs the 3D scene by generating a sparse point cloud. Therefore,

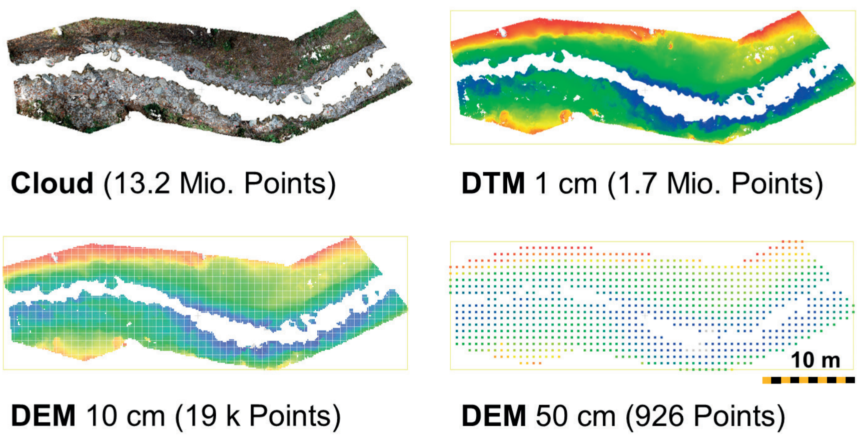


Fig. 4. Example on different processing steps from the dense cloud towards DTM (digital terrain model) and DEM (digital elevation model) and the related number of points (graphic from J.A. Tuhtan)

approximate nearest neighbour (Arya et al. 1998) and Random Sample Consensus (RANSAC; Fischler and Bolles 1987) are used. Feature correspondences place constraints on camera pose orientation, which is reconstructed using a similarity transformation and the minimisation of errors is accomplished by a non-linear least-square solution (Szeliski and Kang 1994; Nocedal and Wright 1999). Triangulation of 3D feature points is used for reconstructing scene geometry in a relative coordinate system.

The described SfM approach from feature extraction to the accurate 3D scene reconstruction is fully automated. The use of Clustering View or Multi-view Stereo (CMVS) (Furukawa and Ponce 2007; Furukawa et al. 2010) and Patch-based Multi-view Stereo (PMVS2) algorithms (Furukawa and Ponce 2007) is an additional process which provides an enhanced density point cloud.

VIRTUAL RIVER (360° PANORAMA)

After checking the photos on quality, the post-processing can be started. The proprietary software Kolor Panotour (www.kolor.com/panotour/) was used for creating the spheres. The single photos were merged and projected to a 360-degree sphere, which is displayed flattened on the computer screen. With this first product, and overview of problems occurring between the different pictures can be estimated. The most obvious mistake in the merged photo were blurred parts that result from objects moving in between two photos, for example clouds, people and water. For this moving objects, the status of a single photo has to be decided to be weighted hundred percent in the merging process, meaning only this object occurring after merging process. The so created spheres were again merged to a virtual tour, linking the individual spheres, depending on their position to each other, together in a row. Also tools for zooming and switching between the spheres were implemented.

RESULTS

The application of the SfM approach based on terrestrial photography turned out to be applicable for the different streams and rivers in the research area, i.e. it was shown that: (I) Monitoring sites along small to mid-sized rivers, like the Tudovka River, can be assessed quite well using terrestrial photography. However it turned out that at some locations vegetation is a limiting factor. (II) Large rivers can be analyzed well, however as images are taken from the right bank to the left bank and vice versa – in this case it turned out to be very difficult to bring both models (for both banks) into one single model. (III) A promising approach to get a model for a large river is taking images taken from a bridge, i.e. the model displays a "cross-section" (e.g. Volga at Rzhev, (Fig. 5).

The quality of a SfM-model is related texture and resolution of the images used to create the model, i.e. high resolution images with complex structures enable higher accuracy in the model. Variation in lightning and individual scenes can influence the texture and quality. It has to be considered that the method is not yet feasible for measurements

Fig. 5. View from the bridge at Rzhev upstream: original image (left) and combination of model and the image (right)

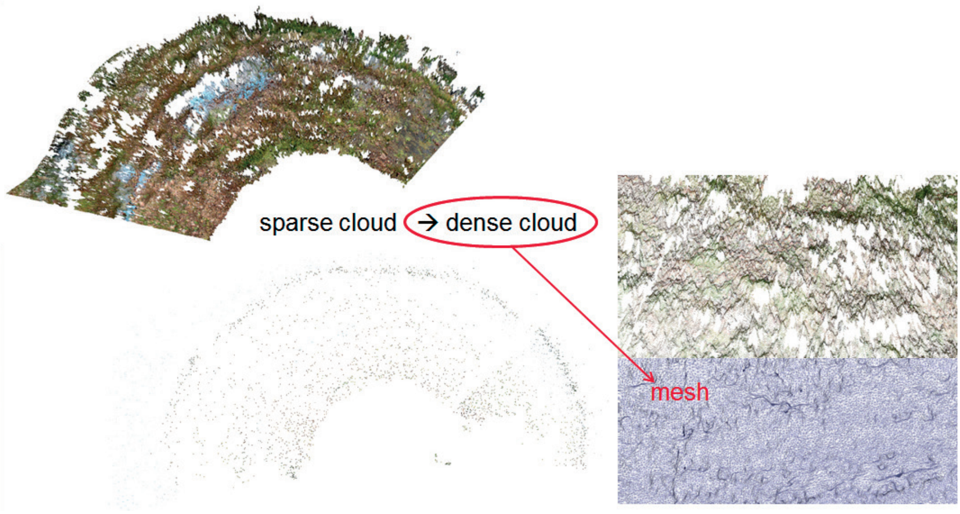


Fig. 6. Example of SFM-analyses of a river bank near Staritsa, which allow detailed assessment of the monitoring sites on macro and micro scale

below the water surface and this application is also limited to transparent shallow water bodies. As the rivers in the research area are lowland systems with an influence of mires, the water surface is the border for the model. However, it enables to assess non-wetted areas with high accuracy (Fig. 6), thus the application of this methodology during the summer low flow period in the headwaters of the Volga is a promising approach for detailed assessments of the river banks along the monitoring sites.

As photos for the virtual tour were not taken using a nodal point adapter, creation of full 360-degree spheres was almost impossible. This problem could be party solved by splitting the spheres into several parts. In the cases were spheres could be created or for the parts of the spheres, photo quality was very good and high resolution was possible. This virtual tour – with the possibility of zooming into scenery, seeing the virtual actual position within space on a map and the moving from sphere to sphere – supports the documentation of certain environmental conditions, such as flow patterns, vegetation, etc. (online supplementary material). Also it is an feasible tool "to come back to field (during analyses in the laboratory)", to check the conditions during a certain sampling campaign, for model validation or to display the environment to project partners who were not able to participate in the field trip.

CONCLUSION AND OUTLOOK

The application of structure from motion (SfM) technique is very useful for the characterisation of riverine systems as

- point clouds and surface models of non-wetted areas

and

- high-resolution (1-10 cm/px) imagery

provide a baseline for modelling and mapping hydromorphology, as local conditions and their change over time (seasonal, after extreme events).

Our study revealed that the methodology can be applied for ground based surveys (especially for small to mid-sized rivers and "cross sections" made from a bridge). However for large scale surveys areal investigations are needed: Civil applications of unmanned aerial vehicles (UAVs) have grown rapidly over the past years. Thus we`d like to highlight their use of remote sensing observations: current applications are archaeology, geography, mining, as well as civil engineering and ecology. UAVs can be leveraged to rapidly create high resolution (up to 1 cm/px) maps of river landscapes and thus have the advantage of being both lean and agile. A lightweight multi-camera system specially designed for

UAVs was tested, generating total coverage spectral imagery. Another advantage is the possibility spectral imagery is mapping of macrophyte stands. High resolution maps of the Normalized Differenced Vegetation Index (NDVI) can be generated using near infrared (NIR) imagery gathered by a multi camera system. This hybrid approach allows for detailed study of the interactions between hydromorphological conditions and aquatic as well terrestrial vegetation.

Environmental intelligence gathering can be applied to increase the scope of scientific surveillance, which reveals new opportunities to detect and quantify complex ecological interactions across a wide spectrum of scales. As the applied imagery methodologies have huge potential for environmental variable classification, future developments will concentrate on information extraction from multispectral imagery as well as feature acquisition and processing in real-time.

REFERENCES

Arya, S., Mount, D., Netanyahu, N., Silverman, R. and Wu, A. (1998). An optimal algo- rithm for approximate nearest neighbour searching fixed dimensions. Journal of the Association for Computing Machinery 45, pp. 891-923.

Astre, H. (2010). [online] SFMToolkit3. Available at: http://www.visual-experiments.com/demos/sfmtoolkit.

Bagheri, O., Ghodsian, M. and Saadatseresht, M. (2015). Reach Scale Application of UAV + SFM method in shallow rivers Hyperspatial Bathymetry. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 40, 77.

Barker, J., Pasternack, G., Bratovich, P., Massa, D., Reedy, G. and Johnson, T. (2010). Method to Rapidly Collect Thousands of Velocity Observations to Validate Million-Element 2D Hydrodynamic Models. AGU Fall Meeting Abstracts 51.

Berni, J., Zarco-Tejada, P., Suarez, L. and Fereres, E. (2009). Thermal and Narrowband Multispectral Remote Sensing for Vegetation Monitoring From an Unmanned Aerial Vehicle. IEEE Transactions on Geoscience and Remote Sensing 47, pp. 722–738. doi:10.1109/TGRS.2008.2010457

Buffington, J. and Montgomery, D. (2013). Geomorphic classification of rivers.

Casado, M., Gonzalez, R., Kriechbaumer, T. and Veal, A. (2015). Automated Identification of River Hydromorphological Features Using UAV High Resolution Aerial Imagery. Sensors 15, pp. 27969–27989. doi:10.3390/s151127969

Charlton, M., Large, A. and Fuller, I. (2003). Application of airborne LiDAR in river environments: the River Coquet, Northumberland, UK. Earth surface processes and landforms 28, 299–306.

Dietrich, J. (2015). Applications of structure-from-motion photogrammetry to fluvial geomorphology.

Eisenbeiss, H. and Zhang, L. (2006). Comparison of DSMs generated from mini UAV imagery and terrestrial laser scanner in a cultural heritage application. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVI-5, pp. 90-96.

Everaerts, J. (2008). The use of unmanned aerial vehicles (UAVs) for remote sensing and mapping. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 37, pp. 1187–1192.

Fischler, M. and, Bolles, R. (1987). Random Sample Consensus: a paradigm for model fitting with applications to image analysis and automated cartography. pp. 726-740 In: Martin, A.F., Oscar, F. (Eds.), Readings inComputerVision: Issues, Problems, Principles, and Paradigms. Morgan Kaufmann Publishers Inc., London.

Flener, C., Vaaja, M., Jaakkola, A., Krooks, A., Kaartinen, H., Kukko, A., Kasvi, E., Hyyppä, H., Hyyppä, J. and Alho, P. (2013). Seamless Mapping of River Channels at High Resolution Using Mobile LiDAR and UAV-Photography. Remote Sensing 5, pp. 6382–6407. doi:10.3390/rs5126382

Flynn, K. and Chapra, S. (2014). Remote Sensing of Submerged Aquatic Vegetation in a Shallow Non-Turbid River Using an Unmanned Aerial Vehicle. Remote Sensing 6, pp. 12815–12836. doi:10.3390/rs61212815

Fonstad, M., Dietrich, J., Courville, B., Jensen, J. and Carbonneau, P. (2013). Topographic structure from motion: a new development in photogrammetric measurement. Earth Surf. Process. Landforms 38, pp. 421–430. doi:10.1002/esp.3366

Furukawa,Y. and Ponce, J. (2007). Accurate,dense, androbust multi-viewstereopsis. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 17-22 June, Minneapolis, USA, 1-8.

Furukawa, Y., Curless, B., Seitz, M. and Szeliski, R. (2010). Clustering view for multi-view ste- reo. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 13-18 June, San Francisco, USA, pp. 1434-1441.

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, C., Heiskanen, A.-S., Johnson, R., Moe, J., Pont, D., Solheim, A. and de Bund, W. van (2010). The European Water Framework Directive at the age of 10: A critical review of the achievements with recommendations for the future. Science of The Total Environment 408, pp. 4007–4019. doi:10.1016/j.scitotenv.2010.05.031

Hugenholtz, C., Whitehead, K., Brown, O., Barchyn, T., Moorman, B., LeClair, A., Riddell, K. and Hamilton, T. (2013). Geomorphological mapping with a small unmanned aircraft system (sUAS): Feature detection and accuracy assessment of a photogrammetrically-derived digital terrain model. Geomorphology 194, pp. 16–24. doi:10.1016/j.geomorph.2013.03.023

Javernick, L., Brasington, J., Caruso, B. (2014). Modeling the topography of shallow braided rivers using Structure-from-Motion photogrammetry. Geomorphology 213, pp. 166–182. doi:10.1016/j.geomorph.2014.01.006

Kaneko, K. and Seiich Nohara (2014). Review of Effective Vegetation Mapping Using the UAV (Unmanned Aerial Vehicle) Method. Journal of Geographic Information System pp. 733–742.

Klein, L., Clayton, S., Alldredge, J. and Goodwin, P. (2007). Long-Term Monitoring and Evaluation of the Lower Red River Meadow Restoration Project, Idaho, USA. Restoration Ecology 15, pp. 223–239.

Lowe, D. (2004). Distinctive image features from scale-invariant keypoints. International Journal of Computer Vision 60, pp. 91-110.

Lucieer, A., Jong, S. de and Turner, D. (2013). Mapping landslide displacements using Structure from Motion (SfM) and image correlation of multi-temporal UAV photography. Progress in Physical Geography 0309133313515293. doi:10.1177/0309133313515293

Mancini, F., Dubbini, M., Gattelli, M., Stecchi, F., Fabbri, S. and Gabbianelli, G. (2013). Using Unmanned Aerial Vehicles (UAV) for High-Resolution Reconstruction of Topography: The Structure from Motion Approach on Coastal Environments. Remote Sensing 5, pp. 6880–6898. doi:10.3390/rs5126880

Mathews, A. and Jensen, J. (2013). Visualizing and Quantifying Vineyard Canopy LAI Using an Unmanned Aerial Vehicle (UAV) Collected High Density Structure from Motion Point Cloud. Remote Sensing 5, pp. 2164–2183. doi:10.3390/rs5052164

Nex, F. and Remondino, F. (2013). UAV for 3D mapping applications: a review. Appl Geomat 6, 1–15. doi:10.1007/s12518-013-0120-x

Nocedal, J. and Wright, S. (1999). Numerical Optimization. Springer, New York.

Ouédraogo, M., Degré, A., Debouche, C. and Lisein, J., 2014. The evaluation of unmanned aerial system-based photogrammetry and terrestrial laser scanning to generate DEMs of agricultural watersheds. Geomorphology 214, pp. 339–355. doi:10.1016/j.geomorph.2014.02.016

Remondino, F., Barazzetti, L., Nex, F., Scaioni, M. and Sarazzi, D. (2011). UAV photogrammetry for mapping and 3d modeling–current status and future perspectives. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 38, C22.

Rice, S., Lancaster, J. and Kemp, P. (2010). Experimentation at the interface of fluvial geomorphology, stream ecology and hydraulic engineering and the development of an effective, interdisciplinary river science. Earth Surface Processes and Landforms 35, pp. 64–77.

Room, M. and Ahmad, A. (2014). Mapping of a river using close range photogrammetry technique and unmanned aerial vehicle system. IOP Conference Series: Earth and Environmental Science 18, 012061. doi:10.1088/1755-1315/18/1/012061

Schletterer, M., Füreder, L., Kuzovlev, V., Zhenikov, K. and Zhenikov, Y. (2016). REFCOND_VOLGA: a monitoring programme for water quality in the headwaters of the Volga River (Tver region, Russia). Revista Eletrônica de Gestão e Tecnologias Ambientais (GESTA) 4/1, pp. 18-40.

Smith, M., Carrivick, J. and Quincey, D. (2015). Structure from motion photogrammetry in physical geography. Progress in Physical Geography 0309133315615805. doi:10.1177/0309133315615805

Smith, M. and Vericat, D. (2015). From experimental plots to experimental landscapes: topography, erosion and deposition in sub-humid badlands from Structure-from-Motion photogrammetry. Earth Surf. Process. Landforms 40, pp. 1656–1671. doi:10.1002/esp.3747

Snavely, N., Seitz, S. and Szeliski, R. (2007). Modeling the World from Internet Photo Collections. Int J Comput Vis 80, pp. 189–210. doi:10.1007/s11263-007-0107-3

Snavely, N., Seitz, S. and Szeliski, R. (2006). Photo tourism: exploring photo collections in 3D, in: ACM Transactions on Graphics (TOG). ACM, pp. 835–846.

Snavely, N., Seitz, S. and Szeliski, R. (2008). Modelling the world from internet photo collections. International Journal of Computer Vision 80, pp. 189-210
ïStumpf, A., Malet, J., Allemand, P., Pierrot-Deseilligny and M., Skupinski, G. (2015). Ground-based multi-view photogrammetry for the monitoring of landslide deformation and erosion. Geomorphology 231, pp. 130–145. doi:10.1016/j.geomorph.2014.10.039

Szeliski, R. and Kang, S. (1994). Recovering 3-D shape and motion from image streams using nonlinear least squares. Journal of Visual Communication and Image Representation 5, pp. 10-28.

Tamminga, A., Eaton, B. and Hugenholtz, C. (2015). UAS-based remote sensing of fluvial change following an extreme flood event. Earth Surf. Process. Landforms 40, pp. 1464–1476. doi:10.1002/esp.3728

Tamminga, A., Hugenholtz, C., Eaton, B. and Lapointe, M., 2015. Hyperspatial Remote Sensing of Channel Reach Morphology and Hydraulic Fish Habitat Using an Unmanned Aerial Vehicle (UAV): A First Assessment in the Context of River Research and Management. River Res. Applic. 31, pp. 379–391. doi:10.1002/rra.2743

Thumser, P., Haas, C., Tuhtan, J. and Schneider, M. (2015). HYDRONES: Hydrosystem Drone Surveying. E - proceedings of the 36th IAHR World Congress 28 June – 3 July, 2015, The Hague, the Netherlands.

Westoby, M., Brasington, L., Glasser, N., Hambrey, M. and Reynolds, J. (2012). Structure-from-Motion photogrammetry: A low-cost, effective tool for geosience applications, in: Geomorphology 179, pp. 300-314.

Wheaton, J., Brasington, J., Darby, S. and Sear, D.A. (2010). Accounting for uncertainty in DEMs from repeat topographic surveys: improved sediment budgets. Earth Surface Processes and Landforms 35, pp. 136–156.

Whitehead, K., Hugenholtz, C., Myshak, S., Brown, O., LeClair, A., Tamminga, A., Barchyn, T., Moorman, B. and Eaton, B. (2014). Remote sensing of the environment with small unmanned aircraft systems (UASs), part 2: scientific and commercial applications. J. Unmanned Veh. Sys. 02, pp. 86–102. doi:10.1139/juvs-2014-0007

Woodget, A. (2015). Quantifying physical river habitat parameters using hyperspatial resolution UAS imagery and SfM-photogrammetry (Doctoral Thesis). University of Worcester.

Woodget, A., Carbonneau, P., Visser, F. and Maddock, I. (2015). Quantifying submerged fluvial topography using hyperspatial resolution UAS imagery and structure from motion photogrammetry. Earth Surf. Process. Landforms 40, pp. 47–64. doi:10.1002/esp.3613

Wu, C. (2007). SiftGPU: A GPU implementation of Scale Invariant Feature Transform (SIFT), [online] Available at: http://cs.unc.edu/~ccwu/siftgpu/
ïWu, C. (2011). VisualSFM: A Visual Structure from Motion System, [online] Available at: http://ccwu.me/vsfm/

Wu, C., Sameer Agarwal, S., Brian Curless, B. and Seitz, S. (2011). Multicore Bundle Adjustment, in: 2011 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), IEEE, pp. 3057-3064.

Received on February 18th, 2017 Accepted on August 10th, 2017

Philipp Thumser is co-founder and managing director of I AM HYDRO GmbH, with its main competence in Investigation And Monitoring of HYDROsystems for better data and to improve understanding of environmental processes. Philipp has an academical background in hydrology and meteorology from the TU Dresden. Philipp also lead and participated in several projects and studies in Europe and abroad. Since 2016 he is also external lecturer at Stuttgart University at the Department of Hydraulic Engineering and Water Resources Management.

Vyacheslav V. Kuzovlev, candidate of technical sciences, associate professor. In 1994 he graduated from Tver State Polytechnic Institute (Russia) in «Open pit mining» and in 2002 he defended his thesis on «Development of Methods for the Environmental Evaluation of the Wise Use of Peatlands». Since 2000 he is working at Tver State Technical University. Research interests: evaluation of the impact of natural landscapes on the hydrochemical regime of riverine systems. Since 2011 he is also the head of the Laboratory of Environmental Monitoring of the Tver Center for Hydrometeorology and Environmental Monitoring (ROSHYDROMET division in Tver region).

Kyrill Y. Zhenikov graduated in 2011 from Tver State Technical University (Russia) with a degree in «Environmental protection and rational use of natural resources». Research interests are focused in the following areas: hydrochemistry and hydrology of surface water, marsh drains, the resources of peat and sapropel ecosystems. Since 2014 he is a postgraduate student at Tver State Technical University and works in international scientific projects.

Prof. Dr. Yuri N. Zhenikov graduated in 1973 at the Kalinin Polytechnic Institute (Russia), with the specialty «Technology and complex mechanization of peat deposits». In 2000 he defended his doctoral thesis «Geoecological basis for the rational use of peat bog resources of the Upper Volga Region». Since 1996 he works in international scientific projects. Research interests are focused in the following areas: the interaction of peat bogs and the environment, the composition and properties of the surface water as well as environmental impact assessment. Since 1973 he is working at Tver State Technical University, in 2004 he became head of the Chair of Nature Management and Ecology (Кафедра Природообустройства и экологии). He also supervises the department of Geology, exploration and technological design of the East European Institute of Peat Business (www.instorf.ru).

Maximilian Boschi, economics student at Leopold-Franzens University in Innsbruck (Austria) and managing director of droneproject.at, an Austrian-based unmanned aerial vehicle (UAV) company founded in 2012. In collaboration with his twin brother Peter Boschi they focus on dynamic aerial based filming as well as on photogrammetric surveys.

Peter Boschi, student of Applied Geosciences at Montanuniversiät Leoben (Austria) and self-employed running a film production company since 2015. His bachelor thesis outlines the UAV-based applications in geosciences.

Dr. Martin Schletterer studied biology, with a focus on zoology and limnology, at the University of Innsbruck (Austria) and graduated in 2007. He obtained his doctoral degree (PhD) for his research on "Benthic Invertebrates and Reference Conditions in East European Running Waters: Case study in the headwaters of Volga River (Tver Region, Russia) and adjacent water bodies" in 2010. He was working on national and international scientific projects since 2003 and his research interests are concentrated in the following areas: monitoring, biodiversity (zoobenthos and other aquatic quality components), investigation of anthropogenic stressors at large spatial scales and in the context of environmental factors as well as river basin management. Since 2009 he is working at TIWAG – Tiroler Wasserkraft AG (Hydropower Planning Department) as head of the group "Ecology" and in this role he is responsible for planning and management of ecological aspects as well as R&D projects. Additionally, Dr. Schletterer has teaching assignments at the Institute for Modelling Hydraulic and Environmental Systems at University of Stuttgart (Germany), the University of Vienna (Austria) as well as at the Universidade de Lisboa (Portugal).

Daniel Karthe[1,2], Katja Westphal[1]
[1]Department Aquatic Ecosystem Analysis and Management, Helmholtz Centre for Environmental Research – UFZ, Magdeburg, Germany
[2]German-Mongolian Institute for Resources and Technology – GMIT, Nalaikh, Mongolia

WATER AND HYGIENE IN THE KHARAA RIVER BASIN, MONGOLIA: CURRENT KNOWLEDGE AND RESEARCH NEEDS

ABSTRACT. The Kharaa River Basin has some of the highest densities of population, agricultural and industrial activities in Mongolia. This puts the naturally limited water resources under pressure in both a quantitative and qualitative perspective. Besides mining, key sources of surface water contamination include large numbers of livestock in riverine floodplains and the discharge of untreated or poorly treated waste waters, both into rivers and by soil infiltration. Since both shallow groundwater and river water are used by people and for livestock, there are at least theoretical risks related to the transmission of water-borne pathogens. Only a very limited number of studies on water and hygiene have so far been conducted in Mongolia, all indicating (potential) risks to water users. However, a lack of current and reliable water microbiology data leads to the need of systematic screening of water hygiene in order to derive conclusions for public health and drinking water management at the local and regional scale.

KEY WORDS: Water; hygiene; Kharaa River Basin; Mongolia

CITATION: Daniel Karthe, Katja Westphal (2017) Water and hygiene in the Kharaa River Basin, Mongolia: Current knowledge and research needs. Geography, Environment, Sustainability (GES Journal), Vol.10, No 3, p. 44-53
DOI-10.24057/2071-9388-2017-10-3-44-53

INTRODUCTION

With a population density of only around 2.0 inhabitants/km^2 (National Statistical Office of Mongolia 2017), Mongolia is the world's most sparsely settled country. However, the combination of a highly continental climate, a growing competition for water from the agricultural, mining and urban sector, and a very uneven distribution of the population result in major water-related challenges. The Kharaa River Basin is not only one of the most densely settled areas of the country, but also characterized by intensive agriculture, livestock farming and mining activities (Karthe et al. 2016). Natural limitations in water availability are exacerbated by deficient water supply and wastewater disposal infrastructures in both urban and more rural regions (Karthe et al. 2016).

In 2000, the Mongolian government committed itself to achieving the Millennium Development Goals. With respect to water and sanitation, the plans are to achieve coverage rates of 80% for 'improved' drinking water sources and 70% for 'improved' sanitation facilities (UNDP, 2010). Current data suggest, however, that these goals may not be met, particularly in rural and peri-urban ger areas

(Sigel 2012; Uddin et al. 2014; UNDP 2010). Ger areas are low-income, partly informal settlements where people live in gers – the traditional Mongolian felt tent – and/or in simple, detached houses. Such a situation is conducive to outbreaks of water-borne diseases; however, empirical data about the microbiological water quality and the incidence of water-borne diseases is very rare.

In the context of a recent research and development project, the scientific base for an integrated water resources management (IWRM) for the Kharaa River Basin was investigated (Karthe et al. 2015a). This included comprehensive investigations of physico-chemical water quality (e.g., Hofmann et al. 2008, 2010, 2011, 2015; Menzel et al. 2011; MoMo Consortium 2009; Pfeiffer et al. 2015). However, so far the monitoring of surface, ground and drinking water did not include the question of water hygiene, despite some indications that this may be a substantial problem (Karthe et al. 2012). The aim of this paper is to synthesize the current state of knowledge on water and hygiene in the Kharaa River Basin, which is an important prerequisite for identifying research needs and planning future investigations into this topic. This paper is a meta-analysis based on existing literature and studies.

WATER AND HYGIENE IN MONGOLIA

Studies outside the Kharaa River Basin

Quality-assured data on water and hygiene is very much limited in Mongolia. In the recent past, only a few scientific studies on the hygienic quality of drinking, ground and surface water in the country has been carried out. Contrary evidence for potential bacterial contamination was found for the Selenge River into which the Kharaa River drains via the Orkhon. Whereas Sorokovikova et al. (2013) describes high concentrations of coliform bacteria, ranging between 227 and 6600 CFU/100ml in March and July 2010, respectively, Mu et al. (2008) did not find any evidence pointing towards elevated concentrations of coliforms in the Selenge River Basin (all samples analyzed by the authors were below the Russian sanitary norm of 50 CFU/100ml). Contrastingly, Sorokovikova et al. (2013) assumed domestic wastewater to a relevant source of microbiological surface water pollution, with elevated levels of fecal enterococci being another indicator. For drinking water, a recent survey on the exposure to water, sanitation and hygiene (WASH) related hazards in the peri-urban ger areas of Ulaanbaatar revealed that during the winter, 36% of the household storage containers were contaminated by E. coli at an average of 12.5 E. coli per 100 ml, which rose to 56% contaminated at an average of 50 E. coli per 100 ml in summer (Uddin et al. 2014). Additionally, a study on the health status of seminomadic pastoralists in Mongolia, who make up around one quarter of the country's total population was carried out during the early 1990s and concluded that diarrheal diseases, which were potentially water-borne, were an important cause of morbidity and mortality (Foggin et al. 1997). It is believed that the "sudden disengagement of the Mongolian state fostered the resurgence of infectious morbidity (…) in the 1990s" (Mocellin and Foggin 2008), i.e. at the beginning of the political and socioeconomic transition period following the collapse of socialism. At that time, digestive tract disorders made up between 7.9% and 18.4% of the total morbidity in Khovd, Khuvsgul and Övörhangay provinces (Mocellin and Foggin 2008).

In a review on emerging infectious diseases in Mongolia, Ebright et al. (2003) reported that the summer season is when most diarrheal diseases are reported. According to this review, about 80% of all acute hepatitis cases in Mongolia are due to the usually food- and waterborne hepatitis A virus. Moreover, the authors mention Salmonella spp. and Shigella spp. as the causative organisms of bacterial diarrhea but add that several other bacteria and viruses could not be detected in Mongolia due to a lack of equipment, laboratory consumables or experienced staff.

CURRENT KNOWLEDGE ON WATER, SANITATION AND HYGIENE IN THE KHARAA RIVER BASIN

Problems related to WASH are discussed at the example of Darkhan, which is not only the largest city in the Kharaa River Basin but also the third largest of Mongolia.

Like other major water supply companies, Darkhan's municipal service provider "Darkhan US SUVAG" (USAG) carries out culture-based tests for indicator bacteria in the drinking water before it enters the city's distribution system. Nevertheless, existing data do not necessarily provide a reliable assessment of the drinking water supplied to the city's population for several reasons: (1) laboratory facilities are inadequate; (2) distribution pipelines are in a poor state (Scharaw and Westerhoff 2011); (3) testing is typically not carried out at the consumer's tap. In smaller towns, a lack of experienced laboratory staff or long distances to the nearest water laboratory may be additional reasons why monitoring is limited.

Water provided to ger residents through pipe-fed water kiosks is officially considered to be an improved and safe source of water (Sigel et al. 2012). However, not all water kiosks (Fig. 1) are pipe-fed, and data from Ulaanbaatar show that water obtained from water kiosks is not always safe to drink from a microbiological perspective, with E. coli concentrations in 2 out of 40 water kiosk samples even exceeding 100 E. coli per 100 ml (Uddin et al. 2014). The ger areas located in the floodplains of the Kharaa River are exposed to high risks as families often use private wells for the abstraction of shallow groundwater. The quality of this water is not monitored, but the likelihood of contamination from unsealed pit latrines and animal excreta, which are partly found in close proximity to private wells, is considerable (Karthe et al. 2012; Sigel et al. 2012).

Almost nothing is known about the hygienic state of surface water in the Kharaa River. However, there are several likely sources of microbiological surface water contamination. Typical point sources of coliform bacteria and pathogens in rivers include wastewater treatment plants and sewer overflows, whereas the diffuse sources with the greatest impact is manure from grazing animals or applied as fertilizer (Reder et al. 2015).

Several wastewater treatment plants are only partly operational or completely dysfunctional, including those of Darkhan and Bayangol (Baruunkharaa) (Fig. 2), two of the largest settlements in the Kharaa River Basin. Many WWTPs were originally equipped with a disinfection stage based on chlorination. Khongor Sum is currently the only municipality where such equipment is operational (Nöh and Böttger 2013).

Fig. 1. Water kiosk in Darkhan

Fig. 2. Dysfunctional chlorination chamber, Sharyngol WWTP

High livestock densities in the floodplains (Fig. 3), and often in direct proximity to the river banks, are another potential cause of microbial water contamination (Reder et al. 2015). However, there are currently no data on either lifestock numbers at the river basin scale or data on surface water microbiology. Surface water microbiology is, however, relevant in the sense that (a) it is typically consumed by animals that live in close proximity to their herders; (b) nomadic and sedentary people living close to rivers use surface water as a drinking water source or for food preparation.

NEEDS AND OPTIONS FOR OPERATIONAL MONITORING OF WATER HYGIENE

Most countries of the world have established legal norms for the monitoring of drinking, surface and ground water, and in many cases, developing and transition countries have followed the example of industrialized countries where a combination of drinking water source protection, efficient water treatment and stringent water quality monitoring has helped to almost eliminate water-related diseases (Castell-Exner 2001; Schoenen 2002).

Regarding microbiological water quality, there are typically clear regulations for drinking water, aiming at the exclusion of any risks to public health. For this purpose, water samples are routinely monitored for indicators of fecal contamination, typically by quantifying coliform bacteria concentrations via culture-based techniques and comparing the results to drinking water standards (APHA et al. 1998; Pitkänen et al. 2007; Rompré et al. 2002). For surface and groundwater, most countries in the world do not have general microbiological quality standards, nor is there a requirement for microbiological quality monitoring (unless such sources are used for drinking or bathing) (Karthe et al. 2016b).

AVAILABLE METHODS

A small set of indicators is typically used for the basic characterization of water hygiene. Total coliforms are bacteria that are grown in or on a medium containing lactose at a temperature of 35°C or 37°C. Fecal coliform –or more correctly– thermotolerant coliform bacteria grow on lactose at a temperature of 44°C or 44.5°C. Normally, more than 95% of the thermotolerant coliforms isolated from water are Escherichia coli, i.e. fecal coliform

Fig. 3. Goats grazing on the river bank

bacteria (Bartram & Padley 1996). The use of the coliform group, and more specifically E. coli, dates from their first isolation from feces at the end of the 19th century. The coliform group includes a broad range of bacteria in terms of genus and species, and precise definition of coliform bacteria differs slightly depending on the country or organization in charge of monitoring regulations (Rompré et al. 2002).

A specific challenge in non-disinfected waters such as surface water is the background flora, which requires the use of sufficiently selective culture media. On the other hand, the analysis of drinking water requires a high level of sensitivity (Pitkänen et al. 2007). Since drinking waters are typically oligotrophic, stressed and starved cells can generate serious limitations due to false negative results or underestimations of contamination (Rompré et al. 2002).

One of the most rapid and widely used culture-based methods for quantifying both total coliform and E. coli is the commercialized Colilert system (IDEXX Laboratories Inc., Portland, ME, USA). While the system performs well for non-disinfected water samples, it may underestimate E. coli concentrations or even provide false-negative results (Pitkänen et al. 2007).

A general disadvantage of culture techniques is the time-consuming sample incubation. At present there are several alternatives or complementary options to the classical methods: flow cytometry, approaches based on RNA/DNA amplification and identification (e.g. PCR, DNA microarrays, pyrosequencing, fluorescence in situ hybridization), immunology-based methods, and biosensor-based methods (Conelly and Baeumner 2012; Ramírez-Castillo et al. 2015). A prerequisite for the detection of low levels of pathogens or indicator organisms in water samples using molecular techniques are both sample concentration steps and the implementation of a discrimination between living and dead microorganisms. Currently, there is a strong research focus on ways to combine such sample pre-treatment steps with the actual detection in automated systems (Gibson et al. 2012; Grabow et al. 2001; Hakenberg et al. 2014; Kunze et al. 2015; Langer et al. 2014).

NEEDS AND PERSPECTIVES FOR WATER HYGIENE MONITORING IN THE KHARAA RIVER BASIN

The current data scarcity about drinking, ground and surface water hygiene in Mongolia is very problematic in the context of national and water resources management planning (Karthe et al. 2015b), since it is currently difficult to assess where and if measures to improve microbial water quality are required. The so far controversial data situation regarding instream coliforms in the Selenge River and morbidity data suggest that there may be problems related to water-borne infections, and the presence of pit latrines close to shallow wells, poorly maintained wastewater treatment plants and large number of livestock in floodplains mean that ground and surface waters potentially get contaminated by harmful pathogens.

The need to improve the availability of quality-assured data on WASH risks requires a systematic survey of ground, surface and drinking water, particularly in locations that are prone to contaminations. It is suggested that such a survey is carried out in two phases: (1) an initial survey looking at total and thermotolerant coliforms as indicator bacteria, using robust and reliable field methods and (2) a more in-depth survey looking at a larger number of pathogens, potentially with more sophisticated detection methods.

Based on the current state of knowledge, an initial assessment of water hygiene in the region would cover the following locations:

- piped drinking water supply systems in major settlements (e.g. Zuunkharaa, Darkhan);
- water kiosks, particularly when they are not connected to centralized supply systems of deep wells;
- wells in floodplain areas where groundwater levels are shallow and there is a risk of contamination due to nearby livestock and/or latrines;
- surface water downstream of municipal wastewater treatment plants and ger settlements located in the floodplains; and
- surface water downstream of major livestock concentrations in the floodplains.

ACKNOWLEDGEMENTS

Work in the Kharaa River Basin was conducted in the context of the research and development project „Integrated Water Resources Management in Central Asia: Model Region Mongolia", funded by the German Federal Ministry of Education and Research (BMBF) in the framework of the FONA (Research for Sustainable Development) initiative (grants no. 033L003 and 033W016). We would also like to acknowledge the support provided by the Project Administration Jülich (PTJ) in this context.

REFERENCES

Anthonj, C., Beskow, S., Dornelles, F. et al. (2014). Water in Urban Regions: Building Future Knowledge to Integrate Land Use, Ecosystem Services and Human Health. Halle/Saale, Rio de Janeiro, Berlin: German National Academy of Sciences Leopoldina, Brazilian Academy of Sciences, German Young Academy, 32 p.

APHA, AWWA, AEF - American Public Health Association, American Water Works Association and Water Environment Federation (1998). Standard Methods for the Examination of Water and Waste Water, 20th ed. Washington D.C.

Batram, J. and Padley, S. (1996). Microbiological Monitoring of Freshwater. In: Bartram, J., Ballance, R. (Eds). Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes, pp. 241-269. London, UK: E&FB Spon on behalf of UNEP and WHO.

Castell-Exner, C. (2001). Das Multi-Barrieren-System: Basis für eine sichere und nachhaltige Trinkwasserversorgung. energie|wasser-praxis 10/2001, pp. 24-29.

Conelly, J.T. and Baeumner, A.J. (2012). Biosensors for the detection of waterborne pathogens. Annals of Bionanalytical Chemistry Vol. 402(1), pp. 117–127. doi:10.1007/s00216-011-5407-3

Ebright, J., Altantsetseg, T. and Oyungerel, R. (2003). Emerging Infectious Diseases in Mongolia. Emerging Infectious Diseases, Vol. 9(12), pp.1509-1515.

Foggin, P. , Farkas, O., Shiirev-Adiya, S. and Chinbat, B. (1997). Health Status and Risk Factors of Seminomadic Pastoralists in Mongolia: A Geographical Approach. Social Science and Medicine, Vol. 44(11), pp. 1623-1647. DOI:10.1016/S0277-9536(96)00273-0

Gibson, K. , Schwab, K., Spencer, S. et al. (2012). Measuring and mitigating inhibition during quantitative real time PCR analysis of viral nucleic acid extracts from large-volume environmental water samples. Water Research, Vol. 46(13), pp. 4281–4291. DOI: 10.1016/j.watres.2012.04.030

Grabow, W., Taylor, M. and de Villiers, J. (2001). New methods for the detection of viruses: call for review of drinking water quality guidelines. Water Science and Technology, Vol. 43(12), pp.1–8.

Hakenberg, S., Hügle, M., Meyer, P., Behrmann, O. et al. (2014). Fenton fragmentation for faster electrophoretic on chip purification of amplifiable genomic DNA. Biosensors and Bioelectronics, Vol. 67, pp. 49-52. DOI:10.1016/j.bios.2014.06.003

Hofmann, J. (2008). Bericht über die Untersuchungen von Grundwasser und Boden auf Schwermetalle und Cyanid in Khongor Sum. DOI: 10.13140/2.1.4306.5928

Hofmann, J., Hürdler, J., Ibisch, R. et al. (2011). Analysis of Recent Nutrient Emission Pathways, Resulting Surface Water Quality and Ecological Impacts under Extreme Continental Climate: The Kharaa River Basin (Mongolia). International Review of Hydrobiology, Vol. 96 (5), pp. 484-519. DOI:10.1002/iroh.201111294

Hofmann, J., Venohr, M., Behrendt, H. et al. (2010). Integrated water resources management in central Asia: nutrient and heavy metal emissions and their relevance for the Kharaa River Basin, Mongolia. Water Science and Technology, Vol. 62(2), pp. 353-363. DOI: 10.2166/wst.2010.262

Hofmann, J., Watson, V., Scharaw, B. (2015). Groundwater quality under stress: contaminants in the Kharaa River basin (Mongolia). Environmental Earth Sciences, Vol. 73(2), pp. 629-648. DOI: 10.1007/s12665-014-3148-2

Karthe, D., Heldt, S., Houdret, A. et al. (2015a). IWRM in a country under rapid transition: lessons learnt from the Kharaa River Basin, Mongolia. Environmental Earth Sciences, Vol. 73(2), pp. 681-695. DOI:10.1007/s12665-014-3435-y

Karthe, D., Heldt, S., Rost, G. et al. (2016a). Modular Concept for Municipal Water Management in the Kharaa River Basin, Mongolia. In: Borchardt D, Bogardi J, Ibisch R (Ed). Integrated Water Resources Management: Concept, Research and Implementation, pp. 649-681. Heidelberg, Germany & New York, USA: Springer.

Karthe, D., Hofmann, J., Ibisch, R. et al. (2015b). Science-Based IWRM Implementation in a Data-Scarce Central Asian Region: Experiences from a Research and Development Project in the Kharaa River Basin, Mongolia. Water , Vol. 7(7), pp. 3486-3514. DOI:10.3390/w7073486

Karthe, D., Lin, P. and Westphal, K. (2016b). Spatial pattern of surface water hygiene at the Holtemme: Investigations in a small catchment with a strong landuse and pollution gradient. In: Chifflard, P., Heller, K., Karthe, D. (Ed). Beiträge zum 47. Jahrestreffen des Arbeitskreises

Hydrologie vom 19.-21. November 2015 in Dresden. Augsburg: Geographica Augustana.

Karthe, D., Sigel, K., Scharaw, B. et al. (2012). Towards an integrated concept for monitoring and improvements in water supply, sanitation and hygiene (WASH) in urban Mongolia. Water & Risk, Vol. 20, pp. 1-5.

Kunze, A., Pei, L., Elsaesser, D. et al. (2015). High performance concentration method for viruses in drinking water. Journal of Virological Methods, Vol. 222, pp. 132–137. DOI:10.1016/j.jviromet.2015.06.007

Langer, M., Wolf, C., Sorge, H. et al. (2014). Forschung für die Wasserinfrastrukturen von morgen. Energie|wasser-praxis 10/2014, pp. 72-75.

Menzel, L., Hofmann, J. and Ibisch, R. (2011). Untersuchung von Wasser- und Stoffflüssen als Grundlage für ein Integriertes Wasserressourcen – Management im Kharaa-Einzugsgebiet (Mongolei). Hydrologie und Wasserbewirtschaftung, Vol. 55(2), pp. 88-103.

Mocellin, J. and Foggin, P. (2008). Health Status and geographic mobility among semi-nomad pastoralists in Mongolia. Health & Place, Vol. 14(2), pp. 228-242. DOI:10.1016/j.healthplace.2007.06.005

MoMo Consortium (2009). Integrated Water Resources Management for Central Asia: Model Region Mongolia (MoMo). Case Study in the Kharaa River Basin. Final Project Report.

Mun, Y., Ko, I., Janchivdorj, L. et al. (2008). Integrated Water Management Model on the Selenga River Basin – status survey and integration (Phase I). Seoul, South Korea: Korea, Environmental Institute. Project report.

National Statistical Office of Mongolia (2017).

Nöh, C., Böttger, S. (2013). MOMO Project—Sub-Project "Waste water disposal for 6 municipalities of the Kharaa River catchment area": research report. tilia Umwelt GmbH, Leipzig. Unpublished report.

Pfeiffer, M., Batbayar, G., Hofmann, J., Siegfried, K., Karthe, D. and Hahn-Tomer, S. (2015). Investigating arsenic (As) occurrence and sources in ground, surface, waste and drinking water in northern Mongolia. Environmental Earth Sciences, Vol. 73(2), pp. 649-662. DOI: 10.1007/s12665-013-3029-0

Pitkänen, T., Paakkari, P., Miettinen, I.T. et al. (2007). Comparison of media for enumeration of coliform bacteria and Escherichia coli in non-disinfected water. Journal of Microbiological Methods, Vol. 68, pp. 522–529. DOI: 10.1016/j.mimet.2006.10.007

Ramírez-Castillo, F.Y., Loera-Muro, A., Jacques, M., et al. (2015). Waterborne pathogens: detection methods and challenges. Pathogens Vol. 4(2), pp. 307–334. doi:10.3390/pathogens4020307

Reder, K., Flörke, M. and Alcamo, J. (2015). Modelling historical fecal coliform loadings to large European rivers and resulting in-stream concentrations. Environmental Modelling & Software, Vol. 63, pp. 251–263. DOI:10.1016/j.envsoft.2014.10.001

Rompré, A., Servais, P., Baudart, J. et al. (2002). Detection and enumeration of coliforms in drinking water: current methods and emerging approaches. Journal of Microbiological Methods,Vol. 49(1), pp. 31-54. DOI: 10.1016/S0167-7012(01)00351-7

Scharaw, B. and Westerhoff, T. (2011). A leak detection in drinking water distribution network of Darkhan in framework of the project Integrated Water Resources Management in Central Asia, Model Region Mongolia. In: Гуринович АД (Ed.) (2011). Proceedings of the IWA 1st Central Asian Regional Young and Senior Water Professionals Conference, Almaty/Kazakhstan, pp. 275-282.

Schoenen, D. (2002). Role of disinfection in suppressing the spread of pathogens with drinking water: possibilities and limitations. Water Research, Vol. 36(15), pp. 3874–3888. DOI: 10.1016/S0043-1354(02)00076-3

Sigel, K., Altantuul, K. and Basandorj, D. (2012). Household needs and demand for improved water supply and sanitation in peri-urban ger areas: The case of Darkhan, Mongolia. Environmental Earth Sciences, Vol. 65(5), pp.1561-1566. DOI: 10.1007/s12665-011-1221-7

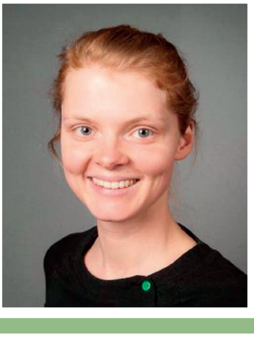
Sorokovikova, L., Popovskaya, G., Tomberg, I. et al. (2013). The Selenge River Water Quality on the Border with Mongolia at the Beginning of the 21st Century. Russian Meterology and Hydrology, Vol. 38 (2), pp.126-133.

Uddin, S., Zifu, L., Gaillard, J. C. et al. (2014). Exposure to WASH-borne hazards: A scoping study on peri-urban Ger areas in Ulaanbaatar, Mongolia. Habitat International, Vol. 44, pp. 403-411. DOI:10.1016/j.habitatint.2014.08.006

UNDP (2010). Country Sector Assessments. UNDP GoAL WaSH Programme. Vol. 2: Governance, Advocacy and Leadership for Water, Sanitation and Hygiene. New York, USA.

Received on May 21th, 2017 Accepted on August 10th, 2017

Daniel Karthe is Associate Professor for Environmental Engineering at the German-Mongolian Institute for Resources and Technology in Nalaikh, Mongolia. He studied Geography at Mannheim University, Germany, and Presidency College, Kolkata, India and obtained his doctoral degree and habilitation at the Institute of Geography at Göttingen University, Germany, in 2009 and 2017, respectively. Since 2010, he has been working as a scientist at the Helmholtz Centre for Environmental Research in Magdeburg, Germany. The main topics of his research include on Integrated Water Resources Management (IWRM) with a specific focus on water quality and the Central Asian region, and on Medical Geography with a specific focus on water hygiene including the application and development of advanced methods for monitoring. He is the speaker of the working group of Hydrology of the German Geographical Society and a steering committee member of IGU's Water Sustainability Commission.



Katja Westphal graduated from the Technical University Cottbus, Germany, now holding an engineering diploma in 'Land Use and Water Management'. During her studies her specialization included freshwater conservation and water sanitation. She has then been doing research on water quality with a focus on nutrients and hygiene in German and Mongolian river basins, which are subject of her doctoral thesis at the Helmholtz-Centre for Environmental Research, Magdeburg, Germany.

Dr. Reena[1]
[1]Political Science Department, Aligarh Muslim University, Aligarh, India
[*]**Corresponding author;** e-mail: reenarn797@gmail.com

TRAGEDY OF CLIMATE AGREEMENTS IN POST-KYOTO PHASE: COPENHAGEN AND BEYOND

ABSTRACT. Climate change is a global environmental problem that is caused due to human-induced increasing levels of the Greenhouse Gases (GHGs). The consequences of climate change are so severe that no country is immune from it. The problem of climate change has created a profound dilemma. There is no global treaty on climate change that can effectively reduce GHGs emission, fix the responsibilities and recompense damages caused to the environment. However, the contentious issue is: To what extent the developed countries should assist the poor countries in meeting the cost of adaptation? The United Nations Framework Convention on Climate Change (UNFCCC) has emphasized on assisting poor and the most vulnerable developing countries. During the Copenhagen Climate Change Conference, various countries adopted Nationally Appropriate Mitigation Actions (NAMAs) to stabilize their emissions of the GHGs. The key intention behind this collective action was to limit the level of temperature below 2oC over pre-industrial level in coming years. But mere pledges are not enough. In fact, more effective measures are needed to cope with rising global temperature. Moreover, significant changes are required in existing climate change policies and programmes. The United Nations (UN) emphasized the principle of Common but Differentiated Responsibility at the Kyoto, Bali, and Copenhagen conferences but the biggest contributors have refused to accept and abide by this principle. At the same time, things are not quite simple as limitation on CO2 mean limitations on economic growth. This has made climate negotiations a very contentious political issue as a result of which the very object of the UN to limit GHG emissions have turned into a tug of war. There is no serious political will to support climate change endeavours. Hundreds of measures have been negotiated in this direction, yet, most of these face problem of implementation. We should act efficiently and quickly to adapt to adverse consequences as projected by the Intergovernmental panel on Climate Change (IPCC). The effective mitigation measures must be taken, worldwide, to tackle climate change urgently. The time is running out. The climate change is the greatest challenge that requires immediate solution. The present paper critically analyses progress made in the field of climate change in the post-Kyoto period and provides to what extent treaties, like, Copenhagen Accord has been successful in dealing with climate change. The work of paper is primarily based on analytical and empirical approach. The significance of the study lies in the fact that climate change is a burning phenomena that the world community facing today. In fact, its solution is required. In this paper authors argue that no country in an isolated manner can cope with the problem of climatic change. In fact, global efforts based on cooperation of all states are very important.

KEY WORDS: climate change, greenhouse gas emissions, Copenhagen Accord, common but differentiated responsibility.

CITATION: Dr. Reena (2017) Tragedy of climate agreements in post-kyoto phase: copenhagen and beyond. Geography, Environment, Sustainability (GES Journal),
Vol.10, No 3, p. 54-65
DOI-10.24057/2071-9388-2017-10-3-54-65

INTRODUCTION

In recent years, climate change has become a severe threat to entire mankind. Uneven consumption of resources in developed countries and growing population of developing countries are chiefly responsible for creating the problem of global warming and climate change. The change in climate is putting stress upon the natural resources. Therefore, people are migrating from one place to another, thus, creating the problem of environmental refugees. The cost of limiting the level of the GHGs is too high, because, the use of coal and gas can adversely affect the economy of poor countries. The developed countries consume around 80 percent of resources, comprising just 20 percent of world's population, while, the developing countries facing extreme poverty do not want to compromise with their growth. Therefore, problem is who will bear responsibility of tackling climate change? There is no global treaty on climate change that can effectively reduce GHGs emission, fix the responsibilities and recompense damages caused to the environment. The UN has adopted the principle of 'Common but Differentiated Responsibility' to resolve the dichotomy in positions of the North and the South. But, the real question is how the UN can work effectively in a world where the largest polluters are, still, not ready to compromise with their economic interests? An effective solution that can truly work should be formulated before time runs out.

LITERATURE REVIEW

(Dessler and Parson 2010) in their work say that there are large differences among nations over how much they are contributing to climate change. The US, currently, emits about 20 percent of the world's CO2 but rapid economic growth in China brought its emission to surpass those of the US. However, in terms of per-capita emissions, china is much behind the US. The industrialized countries' share of world emissions is much larger if we consider cumulative historical emissions. To slowdown the level of GHG emissions, renewable sources of energy must be used. The renewable sources are sustainable and also emit less CO2. Like renewable sources, nuclear fission and fusion are energy sources that emit no CO2 into the atmosphere. The carbon can also be sequestered, biologically, in trees and soils. The market-based regulatory mechanisms are the most prominent new environmental policies adopted over the past two decades. The book focuses on the main forms of market-based policies, 'Carbon Tax' and 'Cap and Trade' system. The advantage of these policies is the flexibility they grant to emitters in responding. These two forms of policies are often proposed as the control element of a climate change mitigation strategies. A carbon tax can be charged on fossil fuels in proportion to their carbon content. The biggest role for direct public expenditure in mitigation policy is government supported research and development of advanced energy technologies.

(Singh 2010) says that adaptation and mitigation are complementary components of a response strategy to climate change. The adaptation will help developing countries to cope with climate change. At the core of most proposals is the reduction of greenhouse gases through reducing energy use and switching to cleaner energy sources. The newly developed and currently available technologies include renewable energy such as hydrogen fuel cells, solar power, tidal and ocean energy. The geo-engineering is another technique that involves large scale engineering of our environment to combat the effects of changes in atmosphere's chemistry. Several non-Kyoto carbon markets are in existence. These are likely to grow in importance and numbers in coming years. The reduction of GHGs is crucially important, because, the CO2 is causing too much damage to the atmosphere.

(Levi 2010) focuses on the Copenhagen climate change conference and its outcomes. He says that now US has changed its policies or programme towards climate change. The Obama administration is taking ambitious steps to limit the level of GHGs at domestic level. This has cleared the road to climate change treaty. For the past years, many argued that developing countries, like, India and China do not want to commit to a new deal. They are simply hiding behind the US. In fact the countries do not want to compromise with their economic interest. However goal of climate diplomacy should be a safe planet rather than a treaty for its own sake. A global target for the reduction of GHGs should be established and divided between developed and developing countries. (Joshi and Linke 2011) emphasized that in developing countries, like, India climate change imposes new challenges that may require negotiating new international and national policies. The issue of development should continue to remain the focus of the global discourses. The sustainable development can be achieved if a balance is struck between economic development resource allocation and social justice. The developing countries are late entrants in the path of development. The nature and scope of the problem of global sustainability has long been recognized but not acted upon because of political considerations. The increasing financial and technological globalization is leading to re-balancing of the current framework of global environmental governance.

(Lal 2011) reviews the achievements made at the Copenhagen Climate Change Conference that could not prove much successful due to different issues raised by developed and developing countries. The developing countries strongly argued that climate fund should not be constructed as an aid but as a response to historical responsibility for past emissions. One of the critical issues raised at Copenhagen Conference was financing. The Conference introduced the issue of funding in a more significant manner. He, further, says urbanization in India is both a necessary input and an inevitable consequence of growth in the multiple transformations that India will undergo over this century.
Moreover, he focuses on impact of climate change on urbanization and emphasizes that a series of coordinated actions are necessary all the way up from the household to states and national level and, further, in the international domain. (Sanwal 2011) in this article points out that the United Nations is best placed to support a common understanding on patterns of resource use that are common for all. He, further, says that we need trans-formative change because we have to deal with the limited capacity of the planet to absorb carbon. The book focuses on the UN Conference on Sustainable Development (2012) that emphasized on green growth. There are limits to the total ecological burden, the planet can sustain. The transition to a low carbon economy will require a new economic model based on changing pattern of consumption and innovation.

(Zedillo Ernesto 2011) estimates different approaches to the control of global problems like

global warming. After more than decade of negotiations and planning, the first binding international agreement to control the emission of GHGs came into effect in the form of Kyoto Protocol. The institutional framework of the Protocol has taken hold solidly in the European Union-Emission Trading Scheme (EU-ETS) which covers almost half of the Europe's CO2 emissions. The ETS demonstrates that international emission trading on a large scale is, politically, and, administratively, feasible. He, also, outlines basic features of Post-Kyoto international global climate policy agreements. (Victor et al. 2012) state that the risk of climate change is rising sharply because the traditional approach of international climate diplomacy has failed to protect the world from climate change. New climate diplomacy should emphasize that CO2 is not the only warming pollutant gas because around 40 percent of current global warming is generated by other types of pollutants: dark soot called black carbon Methane (CH4), Ozone, etc. Around 60 percent of India's soot emissions can be eliminated by replacing traditional stoves that burn unprocessed fire wood and dung with cleaner stoves. The author, further, emphasizes that many governments in developing countries, including Brazil and India, are also doing serious assessment but locally directed assessment are not occurring in the most vulnerable regions in Africa and low lying islands where sea level rise and severe storms are seriously affecting the countries. (Sikka 2012) observes India's stand on climate change problem. To him, India must adopt domestic action to enhance its climate change management. The efforts should be targeted towards achieving time bound outcomes related to energy efficiency. There is a need of technological solution that is appropriate, affordable and truly effective. The National Action Plan on Climate Change proposes eight missions to help the country in adaptation and mitigation of climate change. In this way, the Government of India seeks to make a bold move to prove commitment to mitigate climate change. Besides, India has a legislative agenda for greenhouse gas mitigation which will bring credibility to the actions through domestic political concerns. The Green India mission recognizes that climate change will seriously affect and alter the distribution of natural resources associated with livelihood of the people. This book emphasizes on restoration of ecosystem and habitat diversity. The local communities can play a key role in project governance and implementation. The environment and development must go hand in hand. (Bidwai 2012) argues that two decades after the Rio Earth Summit, despite publication of thousands of research papers which recommended urgent remedial measures, the world has failed to combat the threat of climate change. The Copenhagen and Cancun did not substantially resolve any of the contentious issues. However, the most tangible positive outcome of the Cancun Conference was an agreement to establish a Green Climate Fund. India is emerging as a major power, despite, the persistence of mass deprivation and poverty at home. Yet, there is no genuine domestic debate on how and to what end India should deploy its growing power in dealing with climate change. India can and must play prominent role in tackling global warming and climate change.

(Rayfuse and Scott 2014) examine participation of countries in climate change governance. The climate change governance poses the biggest challenge for international law in terms of participation. The efforts to reduce the emission of GHGs involve complex cooperative and innovative assignments among states, international organizations, sub-national actors, private sector and other stakeholders. With the passage of time, a complex multi-actor and multi-dimensional system of governance has emerged to tackle climate change. The focus of the international response is on the development of a multi-lateral climate change regime. Some 20 years after the adoption of UNFCCC, the international community has been unable to resolve its differences and arrive at a legally binding agreement. The Kyoto Protocol has failed to attract the participation and compliance of major developed economies. The 2009 Copenhagen Climate Change Conference, which was intended to adopt a successor Post-Kyoto instrument ended in failure. The climate change is an issue that connects many domains and has implications for various areas of international law and policy.

AIMS/OBJECTIVES OF THE STUDY

For the present study following objectives have been kept in mind:

- To critically analyse progress made in the field of climate change in the post-Kyoto period.
- To provide an answer to, to what extent treaties, like, Copenhagen Accord has been successful in dealing with climate change.
- To seek out new approaches and possibilities to combat the problem of climate change.

DATA BASE AND METHODOLOGY

Present paper is empirical in nature. It is based on analytical and descriptive methods. It is a data-based research coming up with conclusions which are capable of being verified by observation or experiment. In this regard, the study makes use of both the primary and secondary sources of data. The primary sources have been collected from the Inter-governmental Panel on Climate Change (IPCC) reports, reports and decisions of the Conference of the Parties (COP) of the UNFCCC and the Kyoto Protocol, the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP). The paper is also based on project reports related to the issue of climate change. The secondary sources include various books, articles, research journals. The collected data has been analyzed in order to draw inferences for the study.

Approaches to the study are both quantitative and qualitative. The decision to study climate change politics, especially, during Copenhagen summit is first and foremost based on a theoretical interest in how constructions of meaning influence politics, a passion for climate politics and some familiarity with UN,s work on climate change. I draw upon the literatures of climate change, environmental justice, international relations and political ecology to develop research paper and adopt a self-reflexive approach in my analysis. The interviews, conversations and observations are also a source of data. The need for global cooperation to address global environmental issues has arguably provided greater bargaining power to countries formerly marginalized in the global political economy.

But empirical research on anthropogenic climate change is constrained by two fundamental facts. First, climate change is unprecedented and second, its impacts occur gradually. This implies that neither evidence from recent history nor the near future can directly inform policy. Under such circumstances, empirical research must focus on capturing particular features of future climate change and policy, which, combined with theory, can provide credible out-of-sample predictions. In this way, the proposal will use new data settings and methodologies to causally examine central questions related to climate change mitigation, adaptation, innovation, and impacts in India. Results from this research can help in future climate-related research and various issues regarding the politics of climate change.

DISCUSSION AND RESULT

The Copenhagen and Climate Change

The UN Convention at Copenhagen is regarded as a very important step in the field of climate change. The popularity of the conference is evidenced by the gathering of around 130 heads of government from 191 countries and nearly 35000 delegates including activists, scientists and industrialists, etc. It was during this summit that, for the first time, science of climate change was unanimously accepted by the world community. At the summit, diplomats decided to negotiate a successor to the Kyoto Protocol that could be legally binding over developing countries also. But developing countries, like, India and China, refused to commit to a deal that will be legally binding upon them. To them, developed nations are legally bound to cut their emissions because they are historically responsible for the problem of climate change. On the other hand, the developed countries emphasized that, though, they have created much of the GHGs but developing countries cannot shirk away from responsibilities as they likely to contribute to GHGs concentration on an increasing basis.

According to developed countries, around 40 percent emissions are being added by these countries into the atmosphere in recent years. Therefore, the responsibility must be equitably shared between developed and developing countries (Dutt Gautam 2009a). In other words, developing countries should play more explicit role in limiting the level of the GHGs. They should not leave it, exclusively, on the developed countries by saying that they are historically responsible for creating the problem of climate change (Dutt Gautam 2009b). The Obama Administration took an ambitious step in the form of 'Cap & Trade' and 'Clean Energy Legislation' to limit the CO_2 level at home. The US wants emissions reduction from China and India, also. On the other hand, China and India are demanding that developed countries should commit to cut their GHG emissions by over 40 per cent from 1990 level by 2020. But, the US and other developed countries are not ready to meet this goal. China along with other developing countries is also asking developed countries to provide as much as one per cent of their collective GDP or more than US $ 300 billion, annually, to a fund that can help rest of the world to reduce its emissions and adapt to climate change. The industrialized world is not ready to meet this demand (Michael A. Levi 2009).

What happened to Copenhagen Accord?

The Copenhagen summit can be seen as an important step because this was the last agreement to not only continue with the Kyoto Protocol (expired in 2012), but, also strengthen the carbon emission reduction regime. The summit made it fully clear that unless the developed countries reduce their carbon emissions to 40 per cent of the 1990 level by 2020, it will be very difficult to contain global warming to less than 2°C increase over pre-industrial level. Despite these achievements, the 'Copenhagen Accord' that was produced at the Copenhagen Climate Change Conference was criticized on the grounds that developed countries used it as an instrument to replace the Kyoto with a new climate change regime, which will be legally binding on the poor developing countries, also. Further, the Accord was regarded as a three pages document that does not provide any figure for reduction of the GHGs that developed countries are supposed to take after 2012 on an individual basis or as an aggregate target.

Another critical issue that was much contentious at Copenhagen is related to finance. The Accord emphasized that developed countries should provide $ 30 billion in 2010-12 through global institutions, like, the World Bank. Moreover, it was stated that industrialized countries will together provide $ 100 billion a year by 2020 to the developing world. But, this is a distant possibility as the obligation was only for 'mobilizing' finance and not an assurance of actual fund. The actual fund is also uncertain, hence, not forthcoming, as, the Accord the basis of fund will comprise public and private sectors as well as substitute sources (Martin Khor 2010). Another critical point of the Accord is that while it has provided to check rise in global temperature below 2°C, it does not specify any global plan of emission reduction that can enable this goal to be achieved (T. Jayaraman et al. 2010).Copenhagen was criticized by the environmentalists on the grounds that it failed to deliver a fair, binding and ambitious deal. This was described as an 'important breakthrough' by the US President. There was much debate over the issue of monitoring, reporting and verification of national commitments made by developing countries, particularly, India and China to reduce carbon emissions. This provision was criticized on the ground that any review and verification of domestic carbon is a threat to national sovereignty of the states. The Copenhagen has been criticized as inadequate but the fact cannot be ignored that it is the only treaty that for the first time recognize the need to restrict the warming below 2°C on the basis of equity and sustainable development. It emphasizes on the potential adverse consequences of global warming over poor developing countries and stresses on the need for comprehensive adaptation. In this way, it opens the doors for further negotiations to achieve a goal of restricting global warming to below 2°C (Bert Bolin 2007b). But, it is difficult to achieve this goal in a politically divided world. Hence, the states must understand the severity of climate change and cooperate with each other in achieving the goals as set up by the UN.

Today, the time has come to rethink the model of climate change regime that focuses solely on national emissions rather than on activities that generate the emissions. The present approaches to climate change do not address important drivers of emission of the GHGs i.e. human beings. Since, the global atmosphere is used by all states whether developed and developing, reduction of the GHGs anywhere will help in combating the threat of climate change. The developing countries are poor and not in a position to invest much money in tackling climate change. Therefore, it is required that developed countries should provide financial and technological support to the poor countries.

India is not as affluent as China. It lacks massive capital reserves, unlike China. Brazil presents a different sort of challenge. Its energy system is one of the cleanest in the world, primarily, because of its heavy reliance on hydroelectric power and biomass energy. But, its emission absorption capacity has been greatly reduced due to huge scale deforestation. However, the solution requires that Brazilian government should be financially assisted by developed countries to pay put a stop to cutting down of trees and provided funds for planting trees. An agreement on a long term vision is required to be achieved by climate change regime working under the UN. The mechanisms, like, the CDM that are funding GHG emissions cutting projects must be streamlined by focusing on the Least Developed Countries, too (Bert Bolin 2007c). The UN Convention at the Kyoto has already provided that policies and measures to deal with climate change. It should be cost effective so as to ensure global benefits at the lowest possible cost. In this way, both regulatory measures and economic instruments can be used for reduction of the GHGs. Further, the IPCC has also emphasized on instruments, like, emission trading and carbon taxes that can help in the reduction of the costs of achieving a global target. In this way, the Kyoto was a first major step taken by the UN that introduced economic instruments to achieve specific targets. Despite this, the role of the UN has been criticized on the grounds that it has failed to achieve the desired targets (Bert Bolin 2007d). But the fact cannot be ignored that the Kyoto was a major step of the UN that created a political regime for the prevention of human-induced climate change.

Beyond Copenhagen

After Copenhagen, the UN took another major step at Cancun where decision to set up the Green Climate Fund (GCF) was taken with substantial majority. This fund provided for $ 100 billion to be mobilized by the developed countries jointly per year by 2020 to address mitigation and adaptation needs of developing countries (Anwer Sadat 2011). In Post-Copenhagen phase, further efforts were made at the COP-17 that was held in Durban. Again, the developed countries evaded their climate change responsibilities, although, they account for three-fourth of GHG emissions accumulated in the atmosphere. The states at the conference decided to postpone all significant climate actions, particularly, deep reductions in GHGs emissions of developed countries by 2020. However, such actions are needed before 2020 to save the earth from global warming to keep below 2°C over pre-industrial level (Praful Bidwai 2007a).

Like the Kyoto, the Durban Conference did not provide any legally binding commitments based on Common but Differentiated Responsibility. However, among its major outcomes, the Durban Platform for Enhanced Action (DPEA) can be regarded as an important step. It provided that by 2015 parties to the UNFCCC should negotiate a legally binding instrument that will be implemented by 2020. But postponing large reductions in GHG emissions to 2020 can again create problems. It, further, shifts the burden of combating climate change from the North to the South, despite the fact that the northern world is, chiefly, responsible for emitting large amount of the GHGs in the atmosphere. This is weakening the principle of Common but Differentiated Responsibility as enshrined in the UNFCCC.
Since the Copenhagen Summit 2009, the EU backed by the US has succeeded in ensuring that Common but Differentiated Responsibility, the most significant principle on which the Kyoto Protocol was based, is diluted in any future treaty. The EU and the US have argued that China (which, in absolute terms, not in per- capita, is the largest emitter) and other large developing countries, like, India, Brazil, and South Africa must also be bound, to a smaller extent by legally binding emission limits. They hold that the world has moved on since the Kyoto was negotiated. Now it cannot be divided into two halves the developed and developing countries (Praful Bidwai 2007b).

In the Post-Kyoto period, the UN has made remarkable efforts on a consistent basis. It has organized a number of conferences to find a solution to climate change. But, the track record is not satisfactory due to diverse interests of the countries. The COP-19 of the UN was held in Warsaw, capital of Poland, where negotiations on a new global agreement in 2015 were intensified under the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP). It was emphasised that the agreement should cover mitigation, adaptation, finance, technology development and transfer, capacity-building and transparency of action and support. The countries' should present their intended nationally determined contributions (INDCs) to a global agreement by the first quarter in 2015 in a transparent and clear way. With regard to mitigation action before 2020, countries agreed to strengthen measures to close the gap and a series of technical expert meetings for 2014 were planned. It was decided that developed countries should made efforts to mobilize $ 100 billion annually by 2020 and to convene 129 ministerial meetings on long-term finance every two years from 2014 to 2020. In addition, the Parties agreed that the Green Climate Fund (GCF) should be ready for capitalization in the second half of 2014. Moreover, governments agreed on the Warsaw International Mechanism for Loss and Damage to address losses caused by the impact of climate change in developing countries (The End of Hope. 2010).

At Warsaw, the countries agreed to develop the Warsaw Framework for REDD+ (Reducing Emissions from Deforestation and Forest Degradation), including monitoring and verification rules and measures to enhance the protection of forests (The End of Hope. 2010). In fact, in developing countries, forests are major carbon sinks that help in reduction of the GHGs. However, the main concern of discussions at the conference was to produce an agreement to reduce the level of global carbon emissions so as to check it from exceeding 2°C above the pre-industrial level. But, differences persisted between developed and developing countries over a number of issues related to finance and carbon emission targets. The developed countries emphasized that there should be binding targets for all countries that must be implemented by 2020. But countries, like, India and China were opposed to any binding targets on developing countries because, it is against their developmental concerns. However, a basic pre-requisite to mitigate the threat of climate change is not only finance but also a common understanding of the problem of climate change. The stabilization of the GHGs must be a cooperative endeavour across the globe. At the same time, it is important to recognize countries' differing capabilities to contribute to abetment of climate change. The countries should protect the climate system for the benefit of present and future generations. Each country should adopt national policies and take measures for the mitigation of climate change by limiting its anthropogenic emissions of the GHGs and protecting and enhancing its GHGs sinks. Yet, the prime onus lies with developed countries because they are more affluent and historically responsible for creating this problem (Bert Bolin 2007e).

The Lima Climate Conference achieved a range of important outcomes and decisions where levels of transparency and confidence-building reached new heights. The industrialized countries submitted themselves to questioning about their emission targets under a new process called a Multilateral Assessment. The Lima Ministerial Declaration on Education and Awareness calls on governments to put climate change discourse into school curriculum and climate awareness into national development plans. Another important outcome of Lima was 'Lima Call for Climate Action' that provided a way for final agreement to be signed in 2015 in Paris. Under the 'Lima Call for Climate Action', states are required to submit their carbon reduction targets by mid-2015.

Recently, COP-21 was held in Paris where countries negotiated the Paris Agreement on the reduction of GHGs. This agreement set a goal of limiting global warming to less than 2°C compared to pre- industrial level. The agreement would be legally binding if joined by fifty five countries representing fifty five percent of global GHGs emission.

On 22nd April 2016 (Earth Day) 174 countries signed this agreement that is considered a remarkable achievement. During the conference, India represented the cause of developing countries. It insisted that the developed countries should accept the historical responsibility of having emitted most of the GHGs into the atmosphere. The developing countries should not be burdened with binding carbon emission reduction targets in a manner that hampers their growth. The developing countries are organized under the group G77 and other smaller groups. The four leading developing countries Brazil, South Africa, India and China have formed a group known as the BASIC to put up a common approach and strategy for climate change negotiations. However, the fact remains that the deadlocks between the developed and developing countries are creating hindrances in negotiations over a number of issues, like, the division of responsibility for climate change mitigation mechanisms and actions between developed countries and developing countries. An important shortcoming of the Conference was that no provision was made for financial contribution by developed countries to the GCF. The contribution made by the developed countries to the poor developing countries is nearly $ 10 billion per annum. In this way, like the previous conferences, the outcome of Lima was also not very fruitful as far as the most serious issue is involved.

The significance of the Kyoto Protocol has been greatly undermined by the changing global GHG emissions profile. It has been described as irrelevant for countries that are enjoying significant economic growth after 90s. The countries, like, India and China are emerging as fast growing economies as a result of which there is subsequent change in global emissions profile. Therefore a significant treaty is required to deal with climate change according to changing global emission profile. (Table 1)

Thus the emission of the GHGs from developing countries will inevitably rise due to their requirements of economic growth. Besides, there is little evidence to show that new technologies are immediately available for large scale deployment. There are a number of economic and political factors that limit access to the currently available best technologies to the developing world. Instead of developed countries, the developing countries need to know the extent of 'Carbon Space' that is available to them (Tejal Kanitkar et al. 2009). Hence, the recent negotiations on climate change show that in order to get an effective solution to the problem of climate change, action should be taken at all levels, including, regional and global, involving civil society, women and youth. Education can play an important role in instructing youth about negative consequences of climate change and finding out its solutions. In the meantime, a new agreement should be prepared to find a multi-faceted solution to the complex problem. At the same time, earnest efforts should be made by the UN to resolve disputes that are creating hindrances in climate change negotiations. A country's contribution to GHG emissions should be counted on the basis of per-capita emissions not on the basis of total emissions per country. Moreover, an agreement on climate change should be based on the principle of Common but Differentiated Responsibility and Capacity where developed countries are required to make more efforts to tackle climate change because these countries are more capable financially and technologically. India, being a large country in Asian region should help in tackling climate change. However, the development concerns of all developing countries cannot be de-emphasized. The states should press local authorities, private firms and individuals within their territories to take appropriate actions to tackle climate change. But transformation of international commitments into national policy and further into locally implemented measures can raise some questions. Why should we act when our contribution is hardly discernible or should we really participate in combating climate change when non-participants might benefit without contributing time and resources? (Biel and Lundqvist 2008b). But the fact cannot be ignored that in democratic countries, individual citizens and local communities can play a prominent role in the implementation of climate

Table 1. Figure showing percentage share of countries in global emission of GHGs

1950	1990	1997	2005	2006
US (42.3)	US (23.3)	US (24.2)	US (21.3)	**China (21.8)**
EU (30.1)	EU (19.8)	EU(17.5)	**China(20.3)**	US(20.3)
Germany(8.7)	**China(11.0)**	**China(14.6)**	EU(14.9)	EU(14.5)
UK(8.5)	Russia(10.5)	Russia(6.4)	Russia(5.6)	Russia(5.7)
Russia (7.1))	Japan(5.3)	Japan(5.3)	Japan(4.6)	**India(4.7)**
France(3.4)	Germany(4.6)	**India(4)**	**India(4.5)**	Japan(4.4)
Canada(2.6)	Ukraine(3.3)	Germany(3.9))	Germany(3)	Germany(3)
Ukraine(2.0)	**India (3)**	U.K(2.3)	Canada(2)	Canada(1.9)
Poland(1.9)	UK(2.7))	Canada(2.2)	UK(2)	UK(1.9)
Japan(1.7)	Canada(2.1)	**S Korea(2)**	**S Korea(1.8)**	**S Korea(1.8)**

(Top 10 Emitters)

Source: R. K. Pachauri. (2010), Dealing with climate change: Setting a Global Agenda for Mitigation and Adaptation. TERI, New Delhi.

The above figure focuses on top-10 GHGs emitting countries during 1950 (historic bench mark), 1990, 1997 (Kyoto Protocol adopted), 2005 (Kyoto Protocol entered into force) and 2006 (China superseding the US in absolute terms). The list includes significant growing economies. Historically, developing countries have emitted little. However, they are rapidly emerging as leading players, especially, China with about 11 percent of the global emissions of 1990, doubling to 21.8 percent in 2006. China is being pressurized by the developed nations to accept binding emission reduction targets. China has now surpassed the US to become the world's largest emitter of the GHGs in absolute terms.

change policies. In these countries people enjoy constitutional rights and duties and by making proper use of their rights they can help local and national authorities in the protection of the environment (Zedillo Ernesto 2011b).

CONCLUSION

The change in climate is a global problem, therefore, every state should take initiatives to resolve it. It is a common problem of mankind. All states should participate in an international effort to reduce the level of GHG emissions for the purpose of environmental effectiveness and economic variability and efficiency The UN has rightly figured the high contribution of developed countries in the GHG emissions, hence, imposed binding targets on them. Their per-capita emissions are, even today, significantly, much higher than those of developing countries. Even though, norms of the UN are not binding on developing countries, like, India and China, global pressure is being built up upon these countries to take a start in agreeing to bind emission cuts. Hence, the Post-Copenhagen global climates change policy in moving towards effective participation of both developed and developing countries.

REFERENCES

Anders Beil and Lennart J. Lundqvist. (2008a). From Kyoto to Town Hall: Making International and National Climate Policy Work at Local Level. Earth Scan, London.

Anders Beil and Lennart J. Lundqvist. (2008b). From Kyoto to Town Hall: Making International and National Climate Policy Work at Local Level. Earth Scan, London

Anwar Sadat (2011). Green Climate Fund: Unanswered Questions. Economic and Political Weekly, XLVI (15) 22.

Bert Bolin. (2007a). A History of Science and Politics of Climate Change: The Role of Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Bert, Bolin. (2007b). A History of Science and Politics of Climate Change: The Role of Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge.

Bert, Bolin. (2007c). A History of Science and Politics of Climate Change: The Role of Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge

Bert, Bolin. (2007d). A History of Science and Politics of Climate Change: The Role of Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge.

Bert, Bolin. (2007e). A History of Science and Politics of Climate Change: The Role of Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge.

Dutt Gautam (2009a). A Climate Agreement beyond 2012. Economic and Political Weekly. XLIV (45) 40.

Dutt Gautam (2009b). A Climate Agreement beyond 2012. Economic and Political Weekly. XLIV (45) 40.

Ernesto Zedillo. (2011a). Global Warming: Looking beyond Kyoto. Pentagon Press, New Delhi.

Ernesto Zedillo. (2011b). Global Warming: Looking beyond Kyoto. Pentagon Press, New Delhi.

Jayaraman, T., Tejal Kanitkar and Mario D' Souza (2010). Deconstructing the Climate Blame Game. Economic and Political Weekly, XLV (1) 13.

Kanitkar, Tejal, T. Jayaraman, Mario D' Souza and Prabir Purkayastha (2009). How Much Carbon Space Do We Have? Physical Constraint on India's Climate Policy and its Implications. Economic and Political Weekly, XLIV (41) pp. 35-37.

Martin Khor (2010). The Real Tragedy of Copenhagen. Economic and Political Weekly, XLV (1) 12.

Michael A. Levi (2009). Copenhagen Inconvenient Truth: How to Salvage the Climate Conference. Foreign Affairs. 88 (5) 92.

Praful Bidwai (2011). Durban: Road Nowhere. Economic and Political Weekly. XLVI (53) 10.

The End of Hope. (2010). Economic and Political Weekly. XLV (1) 5.

Will India Change the Climate at Copenhagen (2009), Economic and political weekly. XLIV

LITERATURE REVIEW

Andrew E. Dessler and Edward A. Parson. (2010), Science and Politics of Global Climate Change: A Guide to the Debate. Cambridge University Press, Cambridge, pp. 122-37

S. Singh. (2010), Global Warming. Enclave, New Delhi, pp. 119-67

Sanjoy Joshi and Marlies linke, eds., (2011), Sustainable Development and Climate Change. Academic Foundation, New Delhi, pp. 27-87

B. Suresh Lal. (2011), Current Environmental Issues & Challenges: A Healthy Environment for a Healthy Economy. Serial Publications, New Delhi, pp. 4-12

Ernesto Zedillo. (2011), Global Warming: Looking beyond Kyoto. Pentagon Press, New Delhi, pp. 91-147

Mukul Sanwal (2011), Global Vision for Rio+20 and Beyond, Economic and Political Weekly, XLVI (40) pp. 25-29

David G. Victor (2012), The Climate Threat We can Beat: What it is and how to deal with it, Foreign Affairs 91 (3) pp.112-21

Pawan Sikka. (2012) Climate Change, India in Focus: Mitigating Impacts of Global Warming. Uppal Publications, New Delhi, pp.3-16

Praful Bidwai. (2012), the Politics of Climate Change and the Global Crisis: Mitigating our Future. Orient Blackswan Pvt. Ltd., New Delhi, XI-XIX

Rosemary Rayfuse and Shirley V. Scott. (2014), International Law in the Era of Climate Change. Edward Elgar Publishing Lmt., New Delhi, pp. 2-25

Received on Decembr 19th, 2016 Accepted on August 10th, 2017

Dr. Reena has been awarded and recognized for outstanding contributions to climate change researches from different international bodies. She has more than five years of extensive professional experience in the field of environment. She is associated with different societies and forum at national and international level that are working in the field of environment. Her research work has been on climate change and the role of the United Nations in this field. Being a student of Political Science, she has minutely touched the political aspect of the problem of climate change. She has also developed expertise in Adaptation, mitigation, issues of funding and technology transfer. She has significant number of publications in the form of books, research papers and articles.

Tamara Litvinenko[1*], Kazuhiro Kumo[2]
[1]Institute of Geography RAS
[2]Hitotsubashi University, Institute of Economic Research
[*]**Corresponding author;** e-mail: tamaralit@bk.ru

POST-SOVIET PERIOD CHANGES IN RESOURCE UTILIZATION AND THEIR IMPACT ON POPULATION DYNAMICS IN CHUKOTKA AUTONOMOUS OKRUG (RUSSIA)

ABSTRACT. This study examines changes that have occurred in the resource utilization sector and the impact of these changes on population dynamics in the Chukotka Autonomous Okrug (Russia) during the post-Soviet period. This paper discuss topics of population-dynamics-related differences that have emerged in the region and impacts of these differences on the use of natural resources and the ethnic composition of the population. Through this study, it was shown that changes have tended to be small in local areas where indigenous peoples who have engaged in traditional natural resource use for a large proportion of the population, while changes have been relatively large in areas where the proportion of non-indigenous people is high and the mining industry has developed.

KEY WORDS: Chukotka Autonomous Okrug, indigenous people, non-indigenous people, population dynamics, natural resource utilization, human settlements, intra-regional differences, non-renewable mineral resources, renewable natural resources.

CITATION: Tamara Litvinenko, Kazuhiro Kumo(2017) Post-soviet period changes in resource utilization and their impact on population dynamics in Chukotka autonomous okrug (Russia). Geography, Environment, Sustainability (GES Journal), Vol.10, No 3, p. 66-86
DOI-10.24057/2071-9388-2017-10-3-66-86

INTRODUCTION

The demographic economic systems in the North are extremely unstable. The reasons for this are the region's dependence on the extraction of mineral resources, the fact that most human settlements are company towns, and the extremely high mobility of northern labour forces (Heleniak 1999; Motrich 2006; Petrov 2010). On the other hand, some researchers believe that the presence of northern indigenous peoples who continue to utilize resources in traditional ways has maintained local stability (Mulvihill and Jacobs 1991; Duerden 1992; Khaknazarov 2013). Nevertheless, it is not yet fully clear what characteristics make the local demo-economic systems and settlements in the North stable on the whole, and what kinds of factors have affected this stability. The question of what differences exist at the regional or intra-regional level in terms of instability/stability also remains unanswered. Societal changes in the post-Soviet period, which followed the collapse of the Soviet Union and has seen the implementation of market reforms, have resulted in clear and widening differences between regions in the North, within individual regions, and at the local level (Pilyasov 1996). Because the demo-economic system in the North is dependent on firms that utilize natural resources (Petrov 2010), to understand the aforementioned issues, it is necessary to identify spatial regularities concerning the ways that resource utilization affects population. Furthermore, with regard to ethnic regions, it is also essential to clarify what sort of roles ethnic factors have played in this process of societal change.

STUDY SUBJECTS, METHODS, AND DATA

This study covers the Chukotskii Autonomous Okrug (Chukotka). Chukotka is located in the far northeast of Eurasia, and juts out between the Pacific Ocean and the Arctic Sea. Around half of the Okrug is located north of the Arctic Circle, and the climate is harsh. Chukotka contains 10% of Russia's estimated gold reserves, 16% of its estimated tin reserves, and unique biological resources. It also Russia's most sparsely populated region. Besides non-indigenous people, most of whom are Russian, the region is also home to 16 indigenous minorities of the North, who possess distinctive cultures and use the resources in a traditional way that has remained unchanged for centuries (www.chukotka.org 2014).

The objectives of the study are to shed light on (1) the characteristics of changes in population dynamics in the entire Chukotka region and at the intra-regional level that have occurred as a result of transformation of natural resource utilization in the post-Soviet period and are due to the impact of existing objective and subjective factors, (2) the roles that ethnic factors have played in this process, and (3) conditions that have caused stability and instability of local socioeconomic systems and settlements.

The Far-Eastern economists and economic geographers have conducted various studies. These include studies on the natural resource development process in north-eastern Russia during the 1990s reform period (Pilyasov 1996), the development of the mineral resource industry in Chukotka (Lomakina 2002; Minakir 2006; Lomakina 2009), and characteristics of the development of Chukotka from a sociodemographic perspective and compared with other Far Eastern regions (Zheleznov-Chukotskiy et al. 2005; Motrich 2006; Sidorkina 2014). Despite the existence of such studies, Chukotka remains the Arctic region on which the least research has been conducted (Arctic Council 2013). This study, therefore, is aimed at understanding what sort of interrelationships exist between the transformation of nature resource utilization at different local areas and population dynamics. In this respect, it supplements previous research by classifying transformation in settlements from the impact of resource utilization and listing up criteria that constitute causes of stability and instability of local systems and human settlements. Preliminary survey results from the study have already been published (Litvinenko and Murota 2008; Litvinenko 2013). The goal of this paper is to analyze the empirical data obtained in more detail and draw out general rules and scientific interpretations from the data.

Besides official statistics, this study also employs, as its data, documents in the possession of regional or local government bodies, archives from companies and other sources, and interviews carried out during on-site surveys of regional and local experts and corporate representatives. The authors carried out on-site surveys in August 2007 in the Iultinskiy district and in August 2007 and June 2016 in the town of Anadyr and Anadyrskiy district .

Our method to study the interrelationships between resource utilization and population dynamics at the intra-regional and local levels consisted of several steps (stages):

1) Stage 1: Statistical survey. Included in this stage is the analysis of official statistics for the purpose of shedding light on the interrelationships between population dynamics at the regional, intra-regional, and local levels and ethnic composition (indigenous peoples as a percentage of the total population) during the post-Soviet

period. At this stage, the post-Soviet time periods were determined (economic-crisis period, economic-growth period, and period from 2009 until now), and the development of resource utilization sector was investigated statistically.

2) Stage 2: On-site survey of human settlements and dominant companies in company towns. The purpose of this survey was to shed light on the impact that changes in resource-utilizing enterprises have on population dynamics and residential dynamics. Another objective was to show that there are differences in impact depending on the form of resource utilization (whether based on traditional industries that utilize renewable bioresources, or the mining sector which uses exhaustible mineral resources) and ethnic composition (whether non-indigenous or indigenous peoples are dominant).

At this stage, we identify settlements that have been abandoned by surveying regional or local experts and comparing maps of settlements from the Soviet era with modern maps, identify the reasons why these settlements have been abandoned. Here, in addition to performing a questionnaire survey of the aforementioned regional and local experts and company representatives, we analyzed the company materials to find out new temporary workers' settlements emerged in conjunction with the establishment of new resource-utilizing enterprises and labour migration during the post-Soviet period.

3) Stage 3: The survey data are processed and generalization of the research findings from Stage 1 and Stage 2 is performed. Here we produced a map showing differences in population dynamics that occurred within the region. We also classified changes in human settlements during the post-Soviet period and produced lists concerning the following points: (1) settlement status, (2) characteristics of population dynamics including the population migration process, (3) ethnic composition, (4) interrelationship between resource utilization and employment. By generalizing the results of the investigations, we present criteria that constitute causes of stability and instability in local socioeconomic systems and human settlements.

DEVELOPMENT OF CHUKOTKA DURING THE SOVIET ERA: OVERVIEW

It was during the 1920s that the Soviet government and the Soviet-style management system was established in Chukotka. Later, the sedentary and nomadic economies practiced by the indigenous peoples were gradually combined into state-run cooperatives, a process that was already completed by 1950 (Vasil'ev et al. 1996). According to a population census carried out in 1939, 69% of the total populace were Chukchi, Evens, and Eskimo peoples (Fig. 1).

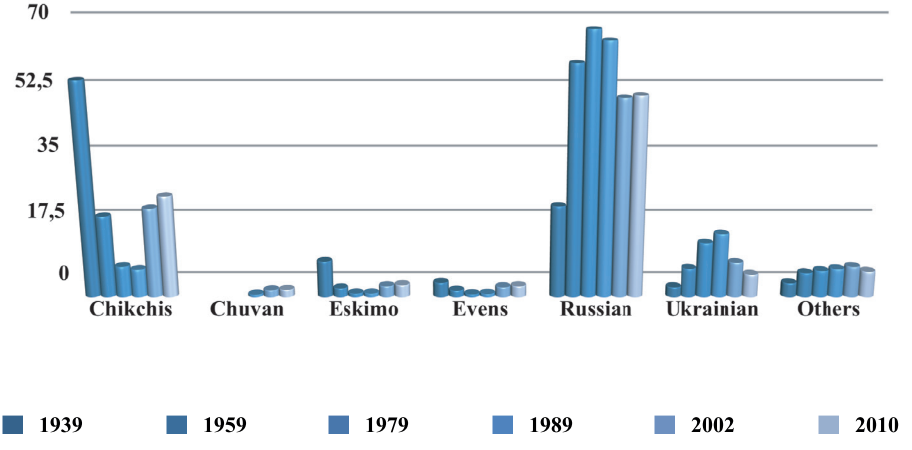


Fig. 1. Ethnic composition of Chukotka: population census data for each year, %

Between 1934 and 1937, vast deposits of tin were discovered on the Pevek Peninsula. Tin and tungsten deposits were also found in Iultin. Industry then began to be developed in Chukotka, with prisoners from the gulags constructed in Chukotka during the 1950s providing the main source of labour. During the Second World War, the region supplied metals and other resources to the military industry, and mining continued to be the region's main industry even after the war.

In 1958, the first gold was produced for industrial purposes, and a gold-mining industry emerged. But it was not until the 1960s that the core components of industry, namely GOKs (mining and processing complexes), industrial firms, power stations, power transmission cables, and transportation infrastructure, were completed. After the gulags were dismantled and their inmates pardoned in 1953, physical measures to encourage people to work in various districts of the Far North were adopted as a means of attracting workers, particularly skilled ones. The construction of new human settlements and the growth of the urban population gave a huge boost to the development of the regional economy and resulted in an inflow of people (Fig. 2). Widespread industrial development in Chukotka continued from the 1970s until the 1980s.

The period from the 1960s until the early 1970s marked the peak in the number of domesticated reindeer (Fig. 3). This was also a time during which the state was active in constructing housing for Chukchi, Eskimo, and Evens people after they settled (Vasil'ev et al. 1966).

During the Soviet era, the population of Chukotka, and the urban population, in particular, climbed as a result of both population inflow and natural increase (because the age structure of the population was relatively young, the rate of natural increase was higher than that of other regions), and reached a peak of 158,000 people in 1990 (Fig. 5 later in this paper). With the influx of non-indigenous people, the ethnic composition the population changed. According to the 1979 population census, Russians as a proportion of the population had risen to 68% (the highest percentage in the history of Chukotka), while the 1989 census put the figure at 66%. At the same time, the increase in Russians coincided with a decline in the Chukchi and other indigenous peoples as a proportion of the population (see Fig. 1).

NATURAL RESOURCE UTILIZATION AND POPULATION DYNAMICS OF THE CHUKOTKA AUTONOMOUS OKRUG DURING THE POST-SOVIET PERIOD

The economic-crisis period: 1990–1998

The transition to a market economy proved to be a painful experience for Chukotka. This was because the situation in the region was wholly and directly dependent

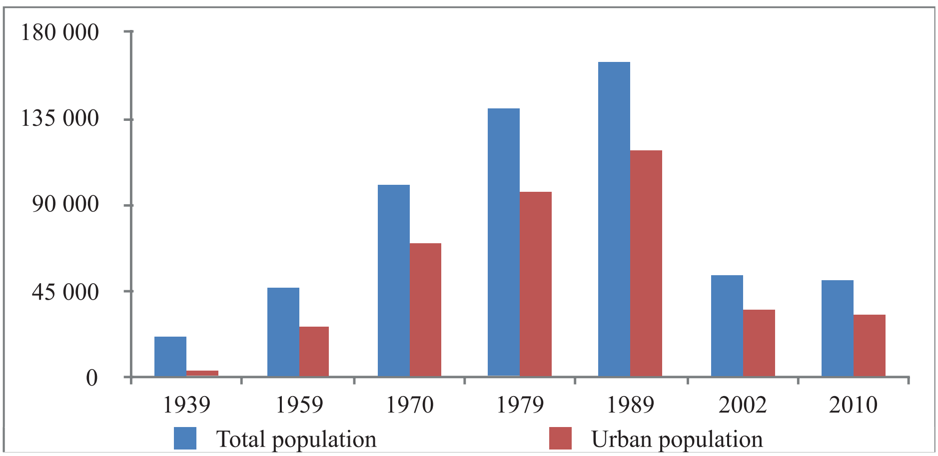


Fig. 2. Total population and urban population of Chukotka: population census data, people

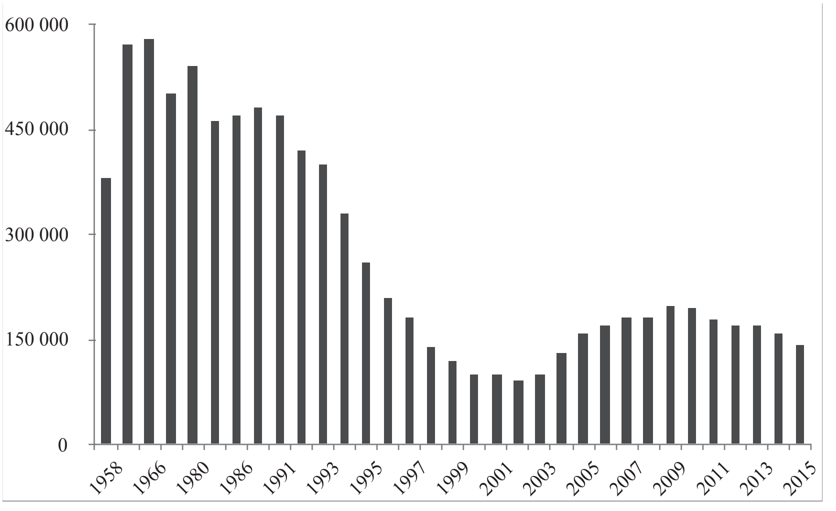


Fig. 3. Number of domesticated reindeer in the Chukotka Autonomous Okrug: 1958–2015

Source: Prepared by the authors based on (Gray 2000) and official statistics. Figures for 2013–2015 are based on the official data from the Government of the Chukotka Autonomous Okrug.

Natural resource utilization and population dynamics of the Chukotka Autonomous Okrug during the post-Soviet period

on the circumstances in Russia. The crisis that swept the region became even more severe as a result of a decline in output from major sectors such as gold and tin mining. As a consequence of the shift to market economics, these industries were no longer profitable, and as a result, operations at the GOKs in Pevek and Iultin, which had been the largest in Chukotka, were suspended during the 1990s, and more than half of the gold mining companies were shut down. During the period from 1990 to 1998, the decline in production in the region was much greater than the Russian average and other eastern regions (Eastern Siberia and the Far East) (Litvinenko 2013), with power production and the output of coal and gold mines plunging by over 50%.

At the time of the economic crisis, traditional forms of economic activity also declined as they no longer benefitted from state support. Fishing catch dropped by 80% (Table 1). To make matters worse, economic conditions in Russia as a whole were worse than ever (Litvinenko 2013), and because support from the regional government was unavailable, the decline in the number of domesticated reindeer was more marked in Chukotka than in any other region of Russia. By 2002, the number of domesticated reindeer had plummeted to less than a fifth of the figure in 1991, to just 90,000. The number of reindeer in Chukotka had never been as low as this during the entire post-war period (Fig. 3).

According to official statistics, by 2000 the average number of people working in the mineral resource mining sector had dropped to 11.5% of the figure in 1992. During the 1990s, the economic crisis rippled out the Chukotka Autonomous Okrug, and due to the absence of state support, many non-indigenous people left in droves for European Russia and other parts of the CIS (Fig. 4).

This massive population outflow was the primary factor behind the fact that the population of the Chukotka Autonomous Okrug declined by more than half between 1990 and 1998 (Fig. 5). On the other hand, between the censuses of 1989 and 2002, the indigenous population increased

Table 1. Trend of natural resources production in the Chukotka Autonomous Okrug, 1990–2015

Year	Output						Change in output			Growth rate (%)		
	1990	1998	1999	2008	2009	2015	1990–1998	1999–2008	2009–2015	1990–1998	1999–2008	2009–2015
Power output, bn kw/h	1,2	0,6	0,6	0,5	0,5	0,6	-0,6	-0,1	0,1	-50	-17	20
Coal mined, 1,000t	1222	333	304	447	346	233	-889	-143	7	-73	47	-32,7
Natural gas extracted, million m3	0	0	0	26,3	25,0	25,4	0	26,3	0,40	0	26,3 times	1.60
Gold mined, 1,000t	17000	6000	4700	20100	31200	31999	-11000	15400	799	-65	4 times	2.6
Fish and other marine products caught, 1,000t	5,1	1	5,7	50,1	38,7	9,4	-4,1	44,4	-28,3	-80	8.8 times	-76
Marine mammals hunted, t	0	0	0	2265	1955	2060	0	2265	10,5	0	2265 times	5.3

Source: Prepared by the authors based on official statistics. 2015 figures and 1999–2015 data for catches of fish and marine mammals are based on information from the Chukotka Autonomous Okrug's Department of Industrial and Agricultural Policy.

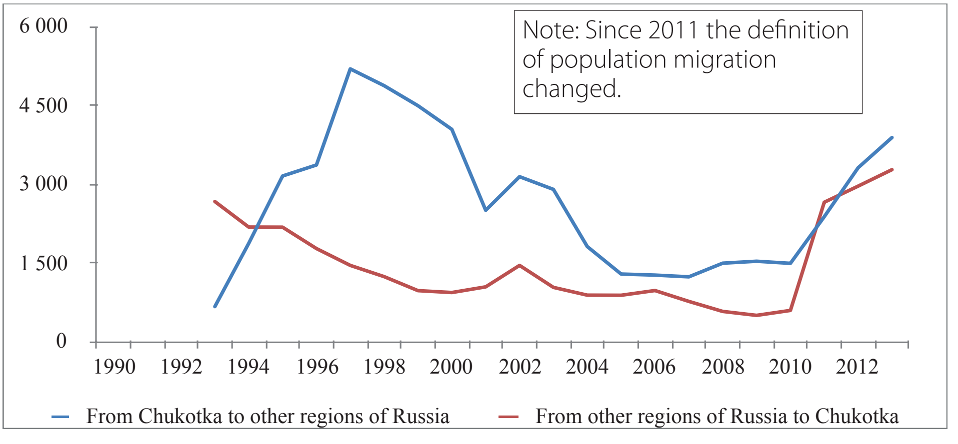


Fig. 4. Population migration to and from Chukotka Autonomous Okrug: post-Soviet period

Source: Internal data supplied by the Russian Federal State Statistics Service

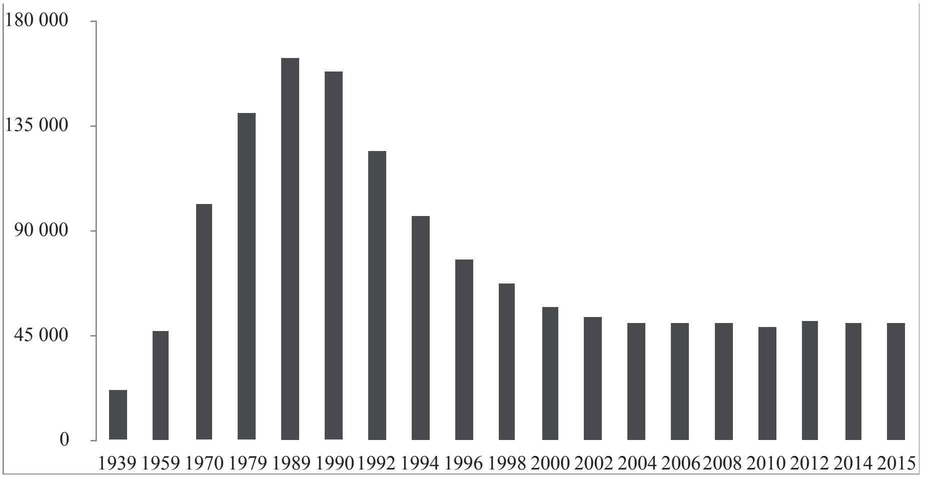


Fig. 5. Population dynamics in the Chukotka Autonomous Okrug: 1939–2015

Source: Official statistics

by 5% to stand at 160,000 at the time of the 2002 census. While the proportion of non-indigenous people such as Russians, Ukrainians, and Tatars dropped, the proportion of Chukchi, Evens, and Eskimo peoples expanded (Motrich 2006).

Here we present insights on the nature of the interrelationships between natural resource utilization, population dynamics, and human settlement during the 1990s, when the economic crisis occurred. These insights were obtained from surveys conducted in the Iultinskiy district.

During the Soviet era, the Iultin Mining and Processing Complex was a company that mined and refined tin and tungsten ore and dust in that district. In 1953, an urban-type settlement was established in Iultin, and in 1954 the Iultinskiy district was organized within Chukotka. From 1991 onwards, market economic conditions saw profitability deteriorate and state support came to an end. For these reasons, the output of the Complex dropped. This decline continued, and wages began to be paid late or not at all. As a result, the number of workers fell. The real incomes of residents dropped sharply, and this, coupled with the extremely harsh climate and the fact that the residents were non-indigenous people without strong ties to the region, meant that the population outflow was inevitable.

In 1994, the decision was made by the Russian federal government to suspend the operations of the refinery and the Iultin and the Svetly Mines, and the government of the Chukotka Autonomous Okrug was obligated to cover the costs of moving the workers out. In 1995, it was also decided to abandon the Iultin urban-type settlement on the grounds that the operations of the Iultin Mining and Processing Complex had been suspended and that it was therefore impossible for people to continue to live there. Furthermore, with the closure of the companies that relied on supplying services to the Iultin GOK, the settlements of Svetlyy, Tranzitnyy, Geologicheskiy, and Vostochnyy were also liquidated (Table 2). The decisions described above were accompanied by the obligation to assist the residents of the settlements with relocating to other parts of Russia. In 1995, the Iultin urban-type settlement was officially abandoned, and in 1998 it was removed from the registry of residential areas. The situation at the Iultin GOK also affected the population of the district in which it was located. Because a large outflow of people occurred between 1990 and 1998, the total population dropped by 59% and the urban population fell by 61% (see Table 2). The close interrelationship between the Iultin Mining and Processing Complex, the populations of the Iultin urban-type settlement, and the Iultinskiy district can be clearly seen in the fact that the coefficient of correlation between the amount of tin

Table 2. Population of the Iultinskiy district, Chukotka Autonomous Okrug, 1990–2015

Year	Population, people						Change in number of people				Growth rate (%)			
	1990	1998	1999	2008	2009	2015	1990 – 1998	1999 – 2008	2009 – 2015	1990 – 2015	1990 – 1998	1999 – 2008	2009 – 2015	1990 – 2015
Total population	31661	8618	8619	6127	5775	5122	-23043	-2492	-653	-26539	-73	-29	-11	-83,8
Urban population	21212	4912	4931	3559	2841	3200	-16300	-1372	-359	-18012	-77	-28	12	-85
Iultin urban-type settlement	5125	0	0	0	0	0	-5125	–	–	-5125	-100	–	–	-100
Vostochnyy settlement	482	0	0	0	0	0	-234	–	–	-234	-100	–	–	-100
Svetlyy settlement	85	0	0	0	0	0	-85	–	–	-85	-100	–	–	-100
Amguema settlement	729	574	617	(1)492	492	435	-112	-125	-57	-294	-15	-20	-12	-40
Egvekinot urban-type settlement	5321	2462	2348	2390	2346	3034	-2973	42	688	-2287	-56	1,8	29	-43

Note 1: Figures are for 2009

Source: Prepared by the authors based on official statistics and data from the Iultinskiy District Official Library Management Department

and tungsten mined at the Iultin GOK and the population of Iultin and Iultinskiy district was 0.9 during the economic crisis of 1990–1997 (calculation using the data from the Archive Department, the Iultinskiy District Administration).

Economic-growth period: 1999–2008

During the economic growth period, the output in Chukotka grew faster than the average for eastern Russia. Between 1999 and 2008, the amount of coal mined increased by 47% (the average rise for eastern Russia was just 3%). The amount of fish caught remained at the same level (but declined by 13% on average in eastern Russia) (Litvinenko 2013). From 2006 onwards, the extraction of natural gas commenced in order to meet local needs (see Table 1). On the other hand, the situation with the amount of gold mined was different. Growth of gold mined in 1999–2006 was much slower than in the Far East and Russia as a whole (Litvinenko 2013). However, with the development of new gold deposits, between 2006 and 2008 the amount of gold mined more than doubled (see Table 1). Furthermore, according to official statistics, the average number of workers in the mineral resource mining sector climbed by 12% between 2000 and 2006.

Subjective factors played a major role in the invigoration of economic activity, and the election of Roman Abramovich as governor of the Chukotka Autonomous Okrug was particularly significant in this respect. As a result of pseudo market measures (the registration in the Chukotka Autonomous Okrug of several companies that were close to Abramovich (and especially that of a Sibneft subsidiary), the revenues of the Okrug increased dramatically. The Okrug's revenues also rose significantly as a result of the income tax paid personally by the governor (it has been reported that the addition of the governor's income tax to the regional coffers resulted in 5.5-times increase in the tax revenues received from residents in 2000 (Litvinenko 2013).

One example of efficient regional management based on the local natural resources was investment for the purpose of developing the fuel and energy complex made by the government of the Chukotka Autonomous Okrug in 2001–2003. The details of this investment are as follows: First, coal-mining companies were modernized and restructured. Next, a gas pipeline with a total length of 104.2 km was laid between the Zapadno-Ozerny gas field and a gas-turbine power plant in Anadyr. The construction of this pipeline enabled the gas field to be used to operate the power station (http://www.chukotka.org, 2014). The construction of wind power stations can also be pointed to as an important component of the investment.

What proved to be effective market policies were, firstly, the development of gold ore deposits (which differed from the placer gold that was almost completely exhausted) based on the prediction that world gold prices would rise and that gold demand would increase in both domestic and foreign markets, and secondly, the luring of domestic and foreign companies to explore promising mining areas. The agreement to sell 75% of the Kupol gold mine to a Canadian mining company Bema Gold that was reached with the government of the Chukotka Autonomous Okrug in 2002 marked the first attempt to attract Western capital to the Okrug. After mining at Kupol commenced in 2008, the amount of gold and silver produced in the region increased substantially (Table 1).

Furthermore, from 2003 the number of domesticated reindeer began to rise (Fig. 3). And as a result of the implementation of a region-specific program to stabilize and spur the development of reindeer husbandry, the number of domesticated reindeer increased by 82% between 1999 and 2008 (Fig. 3).

Meanwhile, the increases in catches of fish and marine animals (see Table 1) can be explained by the presence of state support from the federal and regional government for the traditional natural resource utilization sector. This support included the expansion of catch quotas and increases in the maximum take of marine animals. In the Anadyrskiy district, two new state-run marine-product processing plants went into operation, and in the coastal ethnic settlements, cooperatives for the hunting of marine mammals were organized. Indigenous residents acquired the right to hunt marine mammals and catch fish without the need to apply for licenses. According to official statistics, the annual average number of people engaged in fishing increased fivefold between 2000 and 2006. Even though the companies and cooperatives in the traditional natural resource utilization sector cannot earn a profit from this industry, success was achieved in raising to 25% the proportion of food consumed that is produced in the region (www.rkopin-chukotka.ru, 2010).

At the beginning of the 2000s, pseudo-market, administrative, and state support for regions was extensive, and the role of markets themselves declined in importance. The main revenue source for the integrated finances of the Chukotka Autonomous Okrug was the tax revenue from the governor himself and companies close to him that were registered there. From 2006, however, this situation began to change. The market mechanism began to function more effectively in the development of the region's economy, and the fiscal revenue of the Chukotka Autonomous Okrug started to be augmented by taxes collected in conjunction with new gold mining projects. gold prices in global markets declined, and economic growth in Russia slowed. Despite this, the amount of gold mined in Chukotka remained stable (Table 1). Gold refineries were also constructed at the Kupol, Mayskoe, and Valunistoe mines.

Fig. 6: External appearance of urban streets in Anadyr. Everything has been repainted and roads have been improved. The photos taken by the authors.

When Abramovich was governor, housing was refurbished or replaced, new housing was built, and public infrastructure was reconstructed. The external appearance of residential areas was also improved (Fig. 6). In ethnic settlements, housing was completely rebuilt, and new public infrastructure buildings were constructed.

Despite the success of the resource utilization sector, the population outflow continued (Fig. 4), though at a far slower pace than had been the case in the 1990s. Between 1999 and 2008, the population of the Chukotka Autonomous Okrug dropped by 25%, but this was only half the rate of the decline seen in 1990–1998 (Fig. 5).

From 2009 until now

From 2009 onwards, resource utilization has been developing in two directions. The first was the mining of mineral resources (particularly gold and silver) and the preparation of new mineral resource deposits for development. The development of the largest gold deposits by attracting Russian and foreign capital (Dvoynoy, Kupol, Karal'veem, Mayskoe and Valunistoe) constituted the basic policy for the economic development of the region at this time and remains so today. After 2011,

As a result of the success of the development of the gold-mining sector, from 2010 onwards the Chukotka Autonomous Okrug stood in second or third place in Russia in terms of gold production. The number of indigenous and non-indigenous people of Chukotka working for gold-mining companies more than doubled between 2008 and 2013 (Russia's Arctic… 2016). However, in contrast to the success of the gold-mining industry, the profitability of the Nagonaya mine deteriorated, and the mine was eventually closed in 2015. This caused a decline in the amount of coal mined (Table 1).

Aggressive preparations for the development of new natural-resource-producing areas were made. Among them, priority has been given to the development of the Beringovskiy coal field, which was in a favorable geographic situation as it was located near an unfrozen stretch of the Bering Sea coast. The resources from the Beringovskiy coal field are in demand on world markets and from Asia-Pacific countries. This is because the coal has high calorific value, the reserves are enormous, and most of it is coking coal.

Because of market conditions, there are also plans to resume the mining of tin and tungsten at the Pirkakayskoe deposits in the Chaunskiy district, which is Russia's largest (in 2008, the license was obtained by Severnoe Olovo, a publicly traded company). According to materials from the government of the Chukotka Autonomous Okrug, design work has already begun on a project to mine copper in the Bilibinskiy district in the Baimka zone (Peschanka copper field), with mining set to commence in 2025. From 2020, meanwhile, there are plans to develop the Klen and Kekura gold deposits in the Bilibinskiy district. It is expected that migrant workers from Chukotka, from other regions of Russia, and from other CIS states will provide the main workforce for the development of new mineral resource deposits and their future extraction.

The other developmental direction is based on the utilization of renewable natural resources to promote independent social, economic, and cultural development by indigenous peoples and support their traditional way of life, i.e., on the sustenance of the traditional natural resources sector. This has become a strategic policy of the government of the Okrug. The reason is that this policy is vital to provide the foundation of a system for enabling indigenous people to become self-reliant, and has a big impact on the regional food safety and security. The federal government and regional governments have adopted a policy of establishing conditions for achieving significant development of this sector regardless of its profitability. An example of state support is two regional programs with specific goals: a 2009–2012 program of state support for marine mammal hunting in the Chukotka Autonomous Okrug and a 2010–2012 program of state support for agriculture. These programs were funded by the federal government and regional governments. The state funding for marine mammal hunting was provided through neighboring-territorial cooperatives for indigenous minorities. According to the data from the government of the Chukotka Autonomous Okrug, in 2015 there were eight marine-mammal-hunting cooperatives in 14 settlements in the Chukotsky, Providenskiy, and Iultinskiy districts. State support has served to increase marine mammal hunting (Table 1).

In contrast to the situation with marine mammal hunting, fish catches have dropped by 80% (Table 1). An interview conducted in June 2016 with the head of the Chukotka Autonomous Okrug's Department of Industrial and Agricultural Policy revealed that this was due to a decline in the number of coastal fishing companies from four to two and the fact that in 2008 all the companies that had been engaged in fishing were registered in special economic zones in other parts of the Far East.

State support for reindeer herding has been provided through publicly run companies. The amount of state subsidies provided for reindeer herding that are paid out of the finances of the Autonomous Okrug increased until 2012 but declined after that (Russia's Arctic… 2016). Despite the decision to provide state support, the number of domesticated reindeer has declined since 2006 (Fig. 3). There are a number of reasons for this, including the scrapping of the grace period for slaughter and an increase in the amount of reindeer meat produced.

A regional program with specific long-term goals that runs from 2013 to 2020 and is aimed at developing agriculture and regulating the market for agricultural produce and food products in the Chukotka Autonomous Okrug has been adopted, and this indicates that the traditional resource utilization sector remains an important component of the strategic policy for regional development.

The changes in the resource utilization sector that occurred during this period did not have a major impact on population dynamics. Migration within the region has mainly been from villages to the centers of districts or the center of the Okrug. Population outflow to other regions (Fig. 4) has been largely offset by natural increase, with the total population declining only by a small margin (Fig. 5).

INTERRELATIONSHIPS BETWEEN INTRA-REGIONAL DIFFERENTIATION IN POPULATION DYNAMICS, CHANGES IN HUMAN SETTLEMENTS, NATURAL RESOURCE UTILIZATION, AND ETHNIC COMPOSITION

Differentiation in population dynamics

Changes in natural resource utilization and differences in ethnic composition that occurred during the post-Soviet period had an impact on population dynamics at the district level (Table 3 and Fig. 7). Two districts, Chaunskiy in the north of the Chukotka Autonomous Okrug and Iultinskiy in the northeast, saw the maximum depopulation (80% or more). Most of the settlements in these districts came into existence during the 1950s and 1960s in conjunction with the development of the mining (gold and tin) industry. Most of the residents were Russian people. Indigenous peoples as a proportion of the population of the Chaunskiy district remains lower than in other districts to this day (Table 3 and Fig. 7). The indigenous population of the Iultinskiy district is just over 30% (Table 3). Companies such as the Pevek, Polyarnyy, and Iultin mining and processing complexes closed their doors in the 1990s, and because there were no other places to work, most of the settlements were abandoned between 1995 and 1998, with the remaining residents moving out. In these districts, the population decline was the steepest between 1990 and 2002 (Chaunskiy: 77%, Iultinskiy: 79%). The population outflow continued between 2002 and 2015, and the populations of the districts kept falling, with that of Iultinskiy dropping by 22% and that of Chaunskiy declining by 17%. However, with the creation of new jobs in the energy, gold-mining, and construction sectors, the population became stable compared with the 1990s.

Figure 7 Intra-regional population dynamics and its link to the ethnic breakdown of the population in the Chukotka Autonomous, 1990–2015

Table 3. Population and ethnic composition in the Chukotka Autonomous Okrug, 1990–2015

	Population (number of people)			Population change, %			Indigenous peoples as a proportion of the population, %	
	1990	2002	2015	1990–2002	2002-2015	1990-2015	2002	2010
Chukotka Autonomous Okrug	158056	53824	50759	-66	-5,7	-67,9	31,3	33,4
Anadyr town	17509	11038	14326	-37	29,8	18,2	16,9	17,8
Anadyrskiy district	32609	11169	8788	-65,7	-21,3	-73,1	36,3	39,7
Bilibinskiy district	27956	8820	7825	-68,5	-11,3	-72	21,6	23,3
Iultinskiy district	31661	6634	5122	-79	-22,8	-83,8	308	31,2
Providenskiy district	10019	4660	3737	-53,5	-19,8	-62,7	52,2	56,2
Chaunskiy district	31348	6962	5774	-77,8	-17,1	-81,6	13,1	19,4
Chukotskiy district	6954	4541	4510	-34,7	-0,6	-35,1	82,6	80,4

Note 1: Calculated based on the 2015 district borders.

Source: Based on official statistics. Figures for 2002 and 2010 are based on population census data.

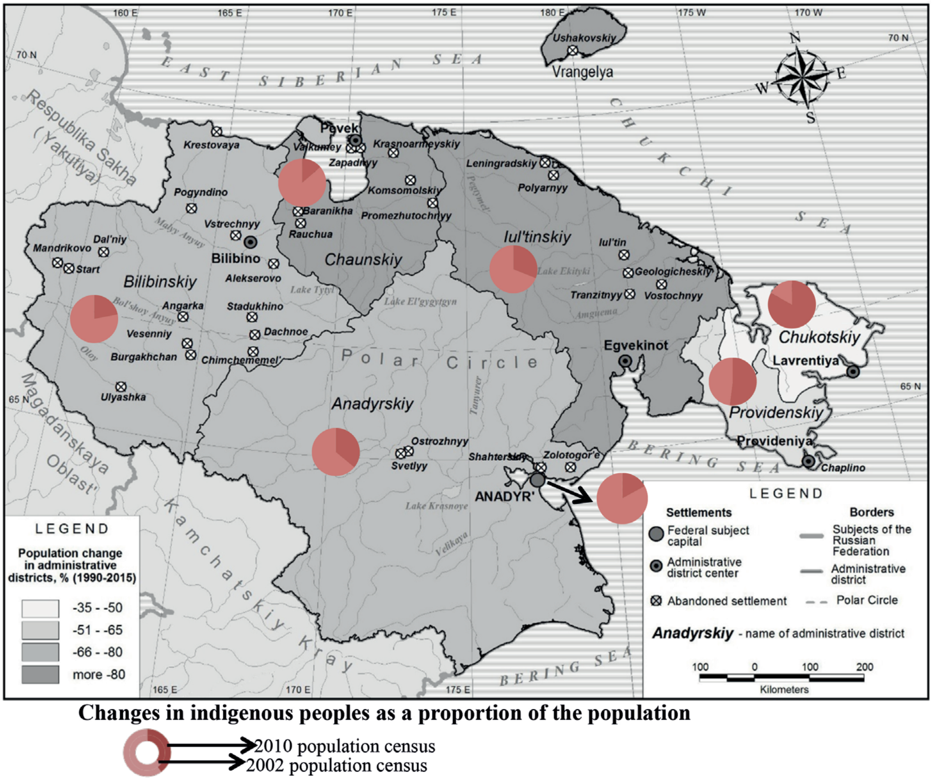


Fig. 7. Intra-regional population dynamics and their link to ethnic breakdown of the population in the Chukotka Autonomous Okrug, 1990–2015

The districts comprising the group in which the population decline was precipitous at 72–73% were the Bilibinskiy and Anadyrskiy districts, which are located in the northwest, west, and south of the Okrug. In these districts, indigenous peoples account for 21–39% of the population (Table 3 and Fig. 7). As a result of the outflow of non- indigenous people and the closure of the settlements for gold miners, the population of the Bilibinskiy and Anadyrskiy districts plunged by over 65% between 1990 and 2002. Although the population decline continued during the 2002–2015 period (see Table 3), the rate of decline fell significantly, and the population stabilized. As was explained earlier, this was due to a drop in population outflow as a result of the development of new gold mines and the subsequent growth in industries supplying power, agricultural products, and food within the region.

In the Providenskiy district, the population decline during the post-Soviet period stayed relatively close to the average. Ten indigenous small-numbered peoples of the North reside in this district, and they form a relatively high proportion of the population, more than half, in fact (Table 3 and Fig. 7). One characteristic of the population in the district is that the decline in population has been caused by both population outflow and natural decrease (1990–2002: 53% fall, 2002–2015: 19% fall). Although there were no new spurs for economic growth, a large drop in population could be avoided thanks to the population trend among the indigenous peoples working in the traditional natural resource utilization sector.

The districts with the smallest population declines during the post-Soviet period were Anadyr town (37% fall) and the Chukotskiy district (34% fall). In the case of the Chukotskiy district, the fact that indigenous peoples dominate the ethnic structure can be regarded as an explanatory factor. The Chukotskiy district is home to Chukchi, Yukagir, Evens, and Itelmens peoples, and they are engaged in traditional natural resource management related to utilization of renewable biological resources. The indigenous population of this district is over 80% (Table 3). Furthermore, the district contains no settlements that have been closed and are no longer inhabited. In the case of Anadyr town, on the other hand, there is another factor behind the relatively small population decline (though the population actually increased by 29% between 2002 and 2015). This is that the town is the capital of the Chukotka Autonomous Okrug. Although the indigenous population of the town is not particularly high as a proportion of its total population, the outflow to other regions of Russia has been offset by an inflow from other parts of Chukotka. This influx has probably occurred because of the high likelihood of obtaining employment in the town and because the social infrastructure is of high quality.

Transformation of human sattlements

Spatial transformation of natural resource use caused the differentiation of settlements. Currently, five types of transformation of human settlements can be observed in the studied region (Table 4). (1) The first type are ethnic rural settlements (villages) that emerged during the Soviet era as a result of the transition by indigenous peoples from pursuing a nomadic existence to living in a fixed location, and are still inhabited today. The population of these villages changed (declined) as a result of natural decrease, the outflow of minority non-indigenous peoples, and a small outflow of indigenous peoples (mainly young ones) to the centre of the district or Anadyr town. However, compared with settlements where most of the residents were Russian, the rate of decline was low, especially during the 1990s. As they had during the Soviet era, the residents of indigenous settlements mainly worked for companies utilizing renewable bioresources or self-employment utilizing these resources. Despite changes in the form of management of natural-resource-utilizing companies (in the Soviet era they were mainly sovkhoz (state-owned farms) whereas now most of them are publicly run single farm enterprises or cooperatives), traditional resource utilization continues to play a central role in these local areas. Examples of such settlements in the Iultinskiy district are the indigenous settlements of Amguema, Vankarem, Nutepelmen, Konergino, and Uelkal. Indigenous residents typically comprised 74–96% of the residents of these settlements. For example, the population of Amguema village declined by 40% between 1990 and 2015, a rate of decline that was less than half that of the Iultinskiy district as a whole (Table 2). Table 4 Types of post-Soviet transformation of human settlements in the Chukotka Autonomous Okrug

(2) The second type is Soviet-period settlements, mainly enjoying the status of a district or Okrug center, inhabited mostly by the Russians. Their population has declined, but they have been maintained as residential areas. Because they have witnessed large population outflows, mainly by non-indigenous people, the population of such settlements declined during the 1990s. For example, the population of the Egvekinot urban-type settlement, which is the center of the Iultinskiy district, dropped by 56% between 1990 and 1998, yet a look at the entire post-Soviet period reveals that the total decline was only 43%, having been softened by a moderate recovery in population since 2000 (see Table 2). What played an active role in maintaining the Egvekinot urban-type settlement and other district centers was the inflow of people from nearby villages, who were attracted by the possibility of securing jobs created by government-funded organizations. The population of Egvekinot stabilized as a consequence of employment by the sea port, construction, and the mining- and energy-resource-utilizing companies serving the local population.

(3) The third type are settlements inhabited by Russians where the population declined dramatically. These residential areas contain both abandoned and still active subdistricts. One example is the Ugolnye Kopi settlement, which includes a residential zone that has now been abandoned but that used to be home to military families and employees of companies providing services to the military. Because the army was disbanded in the 1990s, a large population outflow occurred, but

Table 4. Types of post-Soviet transformation of human settlements in the Chukotka Autonomous Okrug

	Type of transformation	Status of settlement	Ethnic composition	Characteristics of population migration in the post-Soviet period	Population dynamics in the post-Soviet period	Relation to resource use through employment	Examples	Photographs
I	Soviet-period settlements, inhabited largely by indigenous peoples, whose numbers have not changed very much	Village	Mainly indigenous people	Some non-indigenous peoples left during the 1990s. Some indigenous peoples left for the Okrug or district center.	The population is declining, but the margin of decline is considerably smaller relative to settlements with mainly Russian inhabitants	Mainly work for renewable-resource-utilizing companies (fishing, marine-mammal hunting, reindeer herding, etc.) or utilize these resources on a self-employed basis	Amguema village in the Iultinskiy district (photograph)	
II	Soviet-period settlements, considerably depopulated and mainly enjoying the status of a district or Okrug center, inhabited mostly by the Russians	Center of the Okrug or the centers of administrative districts	Mainly Russian people	Significant outflow to other parts of Russia and CIS states during the 1990s	Significant population decline	Mainly work for publicly-financed organizations or companies that utilize non-renewable mineral and energy resources to meet local needs	Anadyr town (photograph), Egvekinot urban-type settlement, center of the Iultinskiy district	
III	Considerably depopulated settlements, with essentially Russian population, where there co-exist abandoned and preserved residential neighborhoods	Urban-type settlement with the status of the district center since 1992	Mainly Russian people	Significant outflow to other parts of Russia and CIS states during the 1990s	Significant population decline	During the Soviet era, companies that supplied the army. During the post-Soviet period, publicly-funded organizations, airport services, and lignite-mining company that meets local needs	Ugolnye Kopi urban-type settlement. There was once an army barracks here but it has been abandoned (photograph)	

	Type of transformation	Status of settlement	Ethnic composition	Characteristics of population migration in the post-Soviet period	Population dynamics in the post-Soviet period	Relation to resource use through employment	Examples	Photographs
IV	Abandoned settlements	Settlements, urban-type settlements	Used to be mainly Russian people	Significant outflow to other parts of Russia and CIS states during the 1990s	Significant population decline during the 1990s. Currently no permanent residents.	Before abandonment of the residential areas, the inhabitants worked mainly in the resource-extraction sector	Iultin urban-type settlement, Iultinskiy district (photograph)	
V	Temporary workers' settlements established in the post-Soviet period (during natural-resource extraction)	None	Mainly Russian people	Temporary inflow of migrant workers from other parts of Russia and CIS states	No permanent residents	Working temporarily mainly for resource-extracting (chiefly gold and silver) companies	Temporary residential area for migrants established near the gold mine in the Valunistoe deposit in the Anadyrskiy district (photograph)	

Source: Prepared by the authors

from 1992 onwards it acquired the status as a centre for the Anadyrskiy district. Employment was provided by government-funded organizations, and the settlement managed to survive thanks to employment at the airport and employment by lignite-mining company. (4) The fourth type are settlements that were once mainly inhabited by Russian and other non-indigenous peoples employed in the mineral-resource mining sector, but have been stripped of their status as towns and now have no residents. After the large companies closed down in the 1990s, the residents, who did not have strong ties to the region, moved away, mainly to central Russia, Russian Far East, or countries of the former Soviet Union, and these settlements were officially abandoned by the Russian government. During the process of conducting on-site surveys and performing investigations using the mapping method, it was found that 31 settlements had been liquidated during the post-Soviet period (Fig. 7). These abandoned residential areas are most numerous in the Chaunskiy district and Bilibinskiy district, where there were numerous settlements that had enterprises involved in the mining of tin and gold and that could be characterized as "company towns." Examples of such settlements would be Iultin, Svetlyy, Tranzitnyy, Geologicheskiy, and Vostochnyy. These settlements disappeared with the suspension of operations by the Iultin Mining and Processing Complex and related companies. Another example is Polyarnyy, which was abandoned following a 1995 decision by the Russian federal government that was made after the closure of the Polyarninskiy Mining and Processing Complex (Fig. 7).

(5) The fifth type are temporary workers' settlements, which have been established during the post-Soviet period to house migrant labour (for extraction of mineral resources). Since 2006, such migrant workers' residences have been constructed in areas where new gold and silver mining projects are underway. An example of this type of temporary workers' settlement would be Kupol. Another would be the temporary-worker residence near the Valuninstoe gold mine in the Anadyrskiy district, where mining takes place all year round. This residential area provides comfortable permanent accommodation for up to 300 people. The number of temporary workers' settlements is on the rise as existing resource-utilization projects continue to be expanded and new ones are launched.

SUMMARY OF THE DISCUSSION

The Chukotka Autonomous Okrug has followed a distinctive process of change during the post-Soviet period. In the 1990s, a large number of mining companies and human settlements were abandoned, and the region's economy suffered the most as a result of the largest population decline of any Russian region. However, it then became an attractive target for investment, with gold mining proving successful. The traditional economic activities of indigenous peoples also underwent development, and their residential areas were completely transformed. The harsh natural conditions, the remote location, the lack of transportation infrastructure, inadequate capital inflows, and weakness in terms of international economic cooperation meant that the profitability of nonferrous-metal and gold mining took a serious hit during the economic crisis of the 1990s. On the other hand, the administration of Roman Abramovich proved successful, and money flowed in for a decade. As a result, new projects to mine gold and silver and extract natural gas were launched, and creation of neighboring-territorial cooperatives and the establishment of publicly run agricultural companies in the traditional resource utilization sector can be identified as providing the sparks for growth.

The post-Soviet period can be summed up by observing the multidirectional changes that occurred in resource utilization at the intra-regional and local levels. The mining of tin and the production of tungsten products ceased completely, coal-mine output shrank to less than a fifth, and power generation for the region halved compared to what it had been initially. Despite the growth that occurred between 2003 and 2009, during the post-Soviet period as a whole, reindeer herding, which forms the basis of traditional natural resource utilization by the Chukchi people, has declined significantly, with the number of domesticated reindeer more than halving. On the other hand, fish catches and marine-mammal hunting have increased dramatically thanks to state support (Table 1). In 2002, wind power began supplying the local area for the first time, and in 2006, natural gas also started to be used. During the post-Soviet period, new mines have been developed, which has increased the amount of gold and silver being extracted. As a result, precious-metal mining now accounts for around 80% of the total mining output, and has established itself as a key industry for the regional economy. Between 1990 and 2015, the total population declined to a third of its former level (Table 3), while indigenous residents as a proportion of the population increased (Fig. 1). Since 2002, however, there has hardly been any change in the population (Fig. 5). The biggest reason for the population decline was changes in the situation with mining companies, and especially their closure during the economic and political crisis of the 1990s, which precipitated a large drop in incomes. State support was no longer available, and the chances of finding jobs were slim. This made living in this northern region incredibly difficult, and led to a large population outflow.

This study has explored the interrelationships between resource utilization and population dynamics at the local level throughout the post-Soviet period. The interrelationships between the two were particularly close during the 1990s. At this time, the close of a large number of mining companies triggered a population outflow and a decline in the total population. In contrast, the period from 2002 has been marked by the success of the resource utilization sector, and this has played a key role in stabilizing the population of the Chukotka Autonomous Okrug.

Ethnic factors have played an extremely important role in the process of interaction between resource utilization and population. In every administrative district, with the exception of the Okrug's center, population dynamics has been characterized by a strong correlation with indigenous peoples as a proportion of the population (at the time of the economic crisis, this correlation was 0.9). The higher the proportion of indigenous peoples at the local area, the smaller the population decline has been during the post-Soviet period. The change has been the smallest in local areas where indigenous peoples engaged in traditional resource utilization make up a large proportion of the population, while the rate of population decline has been the highest in local areas where the mining industry is highly developed and non-indigenous people form a large proportion of the population.

During the post-Soviet period, changes in population dynamics have been akin to a mosaic, with some residential areas being completely abandoned and the exteriors of ethnic settlements and the Okrug's and districts' centers being remodeled. Unlike other parts of eastern Russia, where ethnic Russians make up the overwhelming majority of residents, in the Chukotka Autonomous Okrug, differentiation in spatial changes between settlements with mainly indigenous residents (all of them have been maintained) and settlements with mainly Russian residents (most residential areas have either been abandoned or have been maintained but the population has fallen dramatically) were observed.

Examination of changes in population dynamics in the Chukotka Autonomous Okrug at the regional, intra-regional, and local levels that have occurred in conjunction with changes in resource utilization during the post-Soviet period, allowed confirming the conclusions of previous research that has indicated that the demographic and economic systems in the Arctic regions are unstable (Heleniak 1999; Petrov 2010). Factors, such as settlements dependent on a single company, settlements without the status of a district or regional centers, non-indigenous residents with weak ties to the region, and the employment in the non-renewable mineral resource utilization sector under the market economic system, have caused the population outflows and the abandonment of residential areas, and Chukotka's experience makes it clear that this results in the destabilization of the sociodemographic systems and human settlements in the Arctic regions.

More stable are the local systems where the indigenous peoples working in the traditional renewable resource utilization sector make up an overwhelmingly large proportion of the population. The stability in the development of settlements for indigenous peoples who are engaged in traditional natural resource utilization can be explained by natural factors (the presence of renewable resources in the tundra and taiga zones) and ethnocultural factors (ethnic composition and tendency for traditional natural resource utilization) within the region. On the other hand, the instability of the non-indigenous people residential areas can probably be explained not only by natural and ethnocultural factors but also by external factors (especially national-level political and economic factors as well as global economic factors such as demand for natural resources in world markets).

What has changed during the post-Soviet period is the geographical structure of the Chukotka's economy and human settlement. During the 1990s, residential areas disappeared along with the mining and processing complexes and the scattered infrastructure that accompanied them. From 2000, however, the development of new, non-labour-intensive mining technology has led to the birth of new resource-utilizing companies. These companies were not reincarnations of the old ones. They were started from scratch. They also appeared in geographical locations away from the existing residential zones. Temporary settlements for the workers needed now were also constructed. Just as it always has, the geographical structure of Chukotka's economy and human settlement continue to change, this time as a result of the influence of the new projects to extract mineral resources that are currently in progress.

ACKNOWLEDGEMENTS:

This research was supported by the Grant-in-Aid for Scientific Research (A), Ministry of Education, Science and Culture in Japan (# 26245034), a grant-in-aid from Sumitomo Mitsui Banking Corporation Foundation for International Cooperation (2017), and the Joint Usage and Research Centre Program by the Institute of Economic Research, Hitotsubashi University (2017). The research was also supported by the Russian Foundation for Basic Research, project 15-03-00740 a (T. V. Litvinenko).

REFERENCES

Arctic Climate Impact Assessment. 2005. Published in the United States of America by Cambridge University Press, New York, 2005.

Arctic Council. (2013). Arctic Resilience Interim Report 2013. Stockholm Environment Institute and Stockholm Resilience Centre, Stockholm.

Duerden, F. (1992) Critical Look at Sustainable Development in the Canadian North. ARCTIC, Vol. 45, No. 3 pp. 219-225.

Gornaya ehnciklopediya [Mining encyclopedia]. — M.: Sovetskaya enciklopediya, 1984—1991 . E. Kozlovsky (Ed.) (Pod redakciei E. Kozlovskogo). Vol 2 (Tom 2.) (in Russian).

Gray, P. (2000) Chukotka reindeer husbandry in the post-socialist transition. Polar Research, 19 (1), pp. 31-37.

Haknazarov, S. (2013). Ustoichivoe razvitie malochislennyh narodov Severa: teoretiko-sociologicheskii analiz [Sustainable development of northern minorities: theoretical and sociological analysis]. Vestnik ugrovedeniya.. № 4 (15). pp. 118-124. (in Russian).

Heleniak, T. (1999) Out-Migration and Depopulation of the Russian North during the 1990s, Post-Soviet Geography and Economics, 40:3, pp. 155-205.

Litvinenko, T. (2013). Postsovetskaya transformaciya resursopol'zovaniya i ee vliyanie na dinamiku naseleniya v Chukotskom avtonomnom okruge. [Post-Soviet transformation of resource-use and its impact on population dynamics in the Chukotka Autonomous Okrug]. Izvestiya RAN. Ser. geogr.. № 2. pp. 30-42. (in Russian).

Litvinenko, T. and Takeshi, M. (2008) Social consequences of post-Soviet transformation of natural resources utilization in Chukotka Autonomous Okrug, Russia. Doshisha University Economic Review (Keizaigaku-Ronso). Vol. 60. No. 3. pp. 83-101.

Lomakina, N. 2002 Mineral'no-syr'evoi kompleks v ekonomike Dal'nego Vostoka [Mineral resources complex in the Far-Eastern economy]. Vladivostok: Dal'nauka,. p.135 (in Russian).

Lomakina, N. (2009) Mineral'no-syr'evoj kompleks Dal'nego Vostoka Rossii: potencial razvitiya [The Russian Far-Eastern mineral resources complex: developmental potential]. Khabarovsk: RIOTIP, p. 240 (in Russian).

Minakir, P. (2006) Ekonomika regionov. Dal'nii Vostok [Regional economy. Far-East. A.G. Grinberg (Ed.) (Otv. red. A.G. Granberg).] M.: ZAO Izdatel'stvo Ekonomika, p. 848 (in Russian).

Mulvihill, P. and Jacobs, P. (1991). Towards new south/north development trategies in Canada. Alternatives 10(2). pp. 34-39.

Motrich, E. (2006) Naselenie Dal'nego Vostoka Rossii [The Russian Far-East population]. P.A.Minakir (ed.) Rossiiskaya Akademiya nauk, Dal'nevostochnoe otdelenie, Institut ehkonomicheskih issledovanii. Vladivostok-Khabarovsk: DVO RAN. p. 224 (in Russian).

Oficial'nyi sait Chukotskogo avtonomnogo okruga [Official site of the Chukotka Autonomous Okrug] .07.05.2014. URL: http://www.chukotka.org (in Russian).

Oficial'nyj sait gubernatora Chukotskogo avtonomnogo okruga Romana Kopina [The Chukotka Autonomous Okrug Governor Roman Kopin's official site]. Sobytiya. 05.02.2010 URL: http://www.rkopin-chukotka.ru

Petrov, A. (2010) Post-staple bust: modeling economic effects of mine closures and post-mine demographic shifts in an arctic economy (Yukon), Polar Geography, Vol. 33, No. 1–2, pp. 39–61.

Pilyasov, A. (1996) Zakonomernosti i osobennosti osvoeniya Severo-Vostoka Rossii (retrospektiva i prognoz) [Patterns and features of Russia's North-East development; a retrospective view and forecast]. Magadan: SVKNII DVO RAN. p. 145 (in Russian).

Rossiiskaya Arktika: korennye narody i promyshlennoe osvoenie / V. A. Tishkov (Ed.) Pod obshchei redakciei V. A. Tishkova [Russia's Arctic: indigenous peoples and industrial development]. (2016) Miklukho-Maklay Institute of Ethnology and Anthropology, RAS (Institut etnologii i antropologii im. N. N. Mikluho-Maklaya RAN.) — M.; SPb.: Nestor-Istoriya. 272 p. (in Russian).

Sidorkina, Z. (2014) Territorial'naya organizaciya i social'naya samoorganizaciya naseleniya v slabozaselennom regione. [Territorial organization and social self-organization of population in a sparsely populated region]. Vladivostok: Dal'nauka. p. 240 (in Russian).

Zheleznov-Chukotskii, N., Sekretareva, N., Astahova, T., Zhukova, A. I., Tihomirov YU. and Lozovskaya S. (2005) Prirodnye usloviya i resursy Chukotskogo poluostrova [Natural conditions and resources of the Chukotka Peninsula]. - M.: GEOS. p 503. (in Russian).

Vasil'ev, V., Simchenko, YU. and Sokolova Z. (1966) Problemy rekonstrukcii byta malyh narodov Severa [Aspects of reconstruction of northern minorities' living conditions] Sovetskaya ehtnografiya. № 1. pp. 9-22. (in Russian).

Received on July 04th, 2017 Accepted on August 10th, 2017

Tamara Litvinenko (PhD) is a senior researcher at the department of socio-economic geography, Institute of Geography RAS. Her research areas include social problems of natural resource development in Eastern Russia and tourism and environment relationship in Russia and Japan. She is the author of more than 90 scientific publications. Tamara Litvinenko participated as principal investigator or collaborator in numerous national and international projects supported by the Global Ecological Fund, Ministry for Education, Culture, Sports, Sciences and Technology of Japanese Government, Russian Scientific Fund for Human Studies, Russian Foundation for Basic Research, and Presidium of RAS. Tamara Litvinenko was invited research fellow at the Research Institute for Humanity and Nature (2007) and visiting professor at Doshisha university (2010-2016) in Kyoto, Japan. She was awarded by Honored diploma of the Russian Academy of Sciences (1999) and Honored diploma of Plekhanov Russian Academy of Economics (2006).

Kazuhiro Kumo is Professor at the Institute of Economic Research, Hitotsubashi University (Hitotsubashi IER), Tokyo, Japan. He obtained his Doctoral degree in Economics in 2002 from Kyoto University. He has been the Research Director of the Russian Research Center at Hitotsubashi IER since 2014 and that of the Center for Economic Institutions at Hitotsubashi IER since 2016. During his professional career, he engaged in his research at the University of Birmingham, UK in 2007-2008 and at the University of Oxford, UK in 2013-2014 as a visiting scholar. His areas of research are regional economy, economic geography, demography and migration analysis in Russia and the Former Soviet Union. His latest publications are: "Demography of Russia: From the Past to the Present, Palgrave Macmillan, UK, 2017 (co-authored)", "Research on Poverty in Transition Economies: A Meta-analysis on Changes in the Determinants of Poverty, in Transition Studies Review, 2016".

Dr. Mahvish Anjum[1*], Prof. Nizamuddin Khan[2]
[1] Post Doctoral Fellow, Department of Geography, Aligarh Muslim University, Aligarh-202002, India.
[2] Professor, Department of Geography, Aligarh Muslim University, Aligarh-202002, India
[*]**Corresponding author;** e-mail: mahvishanjum@gmail.com

SPATIAL ANALYSIS ON HEALTH PROBLEMS AMONG UNORGANIZED INDUSTRIAL WORKERS IN AMBEDKARNAGAR DISTRICT, INDIA

ABSTRACT. Health status is one of the important indicators for the welfare of people. People working in unorganized sector are exploited in terms of working hours, low and irregular income, unsatisfactory work conditions, no legal protection and exposed to occupational health hazards. Present study aims to analyze a spatial dimension of occupational health outcomes among the cottage industry workers and their socio-economic conditions. Based on field survey, the result shows that there is an association between different categories of industries and various health problems which leads respiratory and muscular problem, skin disease, and stress and sleep disturbances. There should be a strong provision for occupational health services, carrying out activities in the work place in the aim of protecting and promoting worker's safety, health and well-being.

KEY WORDS: cottage industry, health status, work environment, socio-economic conditions, labour

CITATION: Dr. Mahvish Anjum, Prof. Nizamuddin Khan (2017)Spatial analysis on health problems among unorganized industrial workers in ambedkarnagar district, India. Geography, Environment, Sustainability (GES Journal), Vol.10, No 3, p. 87-98
DOI-10.24057/2071-9388-2017-10-3-87-98

INTRODUCTION

Industrial labors constitute a significant proportion of the total population of any industrial area. Health of these workers is not seen as the absence of disease rather it depends upon a complex web of physical, biological, environmental, economic, social, cultural and possibly even spiritual factors (Hussain 2007). If, as the U.N. Universal Declaration of Human Right declares, all people have a right to a highest level of health attainable, then surely the health of those who produce all valued products used by society is of basic concern (Barten, et al. 1996; Anjum 2012). In developing countries, like India great efforts are directed towards the advancement of cottage industries as these are considered the engine for their economic growth. It is an unorganised sector, mostly run by private establishment. It provides employment for both men and women, mainly those from the lower socio-economic status. People working in unorganised sector are exploited in term of working hours, low and irregular income, unsatisfactory work conditions, no legal protection and exposed to occupational health hazards (Anjum 2012). Health status is one of the important indicators of the welfare of the people. The World Health Organisation says 'enjoyment of high standard of health is one of the fundamental right of every human being'. According to World Health Organisation, over 1000 million people world over are employed in small-scale industries (Saha & et al. 2010). The primary concern regarding labour in the unorganised sector is that most of them live below poverty line. Their access to the basic amenities of life such as food clothing, health, education and other form of security is extremely poor (Papola 1980; Banerji 1985).

Studies show that musculoskeletal problem, diseases of the respiratory system and eye, accident, injuries, skin disease, stress and insomnia etc. are all common among the cottage industry workers (Chamila 2013; Jadab 2012; Saha et al 2010; Baiq et.al. 2005; Rongo et al 2004; John 1919; James et al. 1979).

Despite growing prosperity and spectacular technological advances, the task of ensuring health and well-being for the world is becoming more difficult and expressive and complicated then even before.

An important factor which influenced the health of the people in unorganized sector is the insecurity of the working situation. In Ambedkarnagar district, major source of employment for the rural people is cottage industry after agriculture sector. The cottage industry workers exposed simultaneously to workplace hazards to an unsafe housing environment and a polluted general environment in these areas. Additionally, numerous non-occupational factors such as parasitic and infectious disease, poor hygiene and sanitation, poor nutrition, poverty and illiteracy aggravate these occupational health problems. In the absence of proper occupational health and safety provision the employees are suffered adverse health impacts.

Occupational health is essentially preventive medicine. Both have the same aim of prevention of diseases and maintenance of the highest degree of physical, mental and social well-being of workers in all occupations. Occupational health therefore is the application of preventive medicine in all places of employment (Nalini 2009). International Labour Organisation (ILO 2013) reported that in the United State, skin diseases, hearing loss, respiratory condition were the three leading diseases among the 224,500 reported cases of non-fatal occupational illness in 2009. The WHO estimates occupational health risks as the tenth leading cause of mortality and morbidity.

In the present work an attempt has been made to explore conditions of work and work environment in unorganized sector, and spatial pattern of the health status of workers in Ambedkarnagar district. Current study also aims to establish a relationship between the health status and socio-economic status of the workers employed in cottage industry sector.

Although, different studies reveal various aspects of health in small-scale and cottage industry sector in different areas, no study yet has been made in search of spatial variation in health problems among cottage industry workers in Ambedkarnagar district.

DATABASE AND METHODOLOGY

The study is mainly based on primary sources of data which were collected through field survey from the different blocks of Ambedkarnagar district with the help of questionnaire interview. The field work was conducted during the year 2012 and 2013. For the selection of sample 'stratified random sampling' was adopted. There were a total of 1279 cottage industrial units registered with the District Industries Office, which is spread unevenly across the nine blocks. Out of these units a total of 444 units have been selected purposively for sampling process. These 444 units have been grouped into nine categories on the basis of product type. About 15 per cent units have been selected from each group on random basis. The entire nine blocks have been included in the sample according to the relative strength of their existing industrial units. Altogether, 77 units were selected for the present study and 257 workers were surveyed in these units. The health problems divided into three sections: ergonomic, systemic and psychological problem. Ergonomics is a physiological link between the worker and his environment. The various systemic problems included respiratory and skin diseases. The psychological problems are examined in term of stress and sleep. After the completion of data collection, the data was processed after necessary checking and editing. The data have been analysed both quantitatively and qualitatively. In analysing data, statistical techniques such as simple percentage, Z-score, Composite Z-score have been used to deduce the association among variables, in order to reach conclusion. For showing a clear picture the percentage value of all the relevant variables is presented through choropleth maps prepared by GIS Arc-View (3.2)

Z-SCORE AND COMPOSITE Z-SCORE TECHNIQUE

In order to reach standardisation, the raw data for each variable has been computed into standard score. It is commonly known as Z value or Z-score. The scores measure the departure of individual observation from the arithmetic mean of all observations; expressed in comparable form. The formula is:

$$Z_{ij} = \frac{X_{ij} - \overline{X}_i}{\delta_i}$$

Where,
Zij= Standardised value of the variable i in block j.
Xij = Actual value of variable i in block j.
Xi= Mean value of variable i in all blocks.

In the second step, average value of Z-score of all the variable (28 variables of socio-economic status) have been calculated block-wise which may be called as Composite Z-score (CS) for each block and may be expressed as:

$$CS = \frac{\sum Z_{ij}}{N}$$

Where,
CS is composite score,
N refers to the number of indicators (variables),
∑Zij indicates Z-score of all variables i in block j.

STUDY AREA

Ambedkarnagar is located at 26.02oN latitude and 79.7oE longitudes and one of the district of Uttar Pradesh state of India. Total area of Ambedkarnagar district is 2520 sq. km. Its total population is 2026876 of which 50.57 per cent are male and 49.43 per cent are females. Its 90 per cent population lives in small farming villages. There are 3955 villages. Because of the disperse nature of this hamlets and small village, the distribution is divided into 9 blocks: Akbarpur, Tanda, Bhiti, Katehri, Jalalpur, Jahangirganj, Baskhari, Bhiyaun and Ramnagar (Census of India 2001).

RESULTS AND DISCUSSION

GENERAL PROFILE OF THE WORKERS

The paramount reason for the need to preserve and encourage the cottage industry sector is the human factor involved in it. As far as, an industry is concerned, its workforce is an important factor in determining the productivity of the unit. Present study reveals that majority of the workers (87.55 per cent) in the cottage industry are male while female workers contribute only 12.45 per cent. On an average, female participation is low in the cottage industry due to technological advancement, educational level and social attitude. Mechanisation of cottage industry replaces the female workers due to lack of technical skills. In rural areas of the district female faces restriction to work outside the households, this tends to be viewed as degrading the family status. An analysis on the age of workers reveals that the average age of the workers is 29 years. It is observed from the table 1 that more than 66 per cent workers in cottage industry belong to the age-group of 15-35 years. A little over 8 per cent of the workers under study are above 45 years. As far as the religion-wise distribution of workers is concerned the information shows that majority (69.65 per cent) of workers in sampled cottage industries are Hindus and only 30.35 per cent are Muslim workers in the sampled units. Caste has been an important determiner of the process of social stratification in our country. Table.1 gives an idea about caste-wise distribution of cottage industry workers. Almost 81 per cent workers working in the sampled cottage industries belong to the castes other than the higher castes. Education is the basic necessity of the people at present. The sampled data from field survey shows that 77.04 per cent of the workers are educated. Table 1 further depicts that about 33.85 per cent have primary and middle level education, 19.07 per cent high school pass, 14.40 per cent intermediate level, 9.73 per cent are graduate and above.

Table 1. General Profile of the Workers in Cottage Industry

General Characteristics		Percentage
Age	15-25	36.19
	26-35	30.74
	36-45	24.51
	More than 45	8.56
Sex	Male	87.55
	Female	12.45
Religion	Hindu	69.65
	Muslim	30.35
Caste	General	19.07
	OBC	66.15
	SC/ST	14.79
Educational Level	Uneducated	22.96
	Primary/ middle	33.85
	High school	19.07
	Intermediate	14.40
	Graduation	8.56
	Others	1.17

Source: Based on Field Survey, 2012

LINK BETWEEN WORK AND THE LIVING ENVIRONMENT

Work environment in developing countries are markedly different from those in highly industrialised nations, with the result that radically differing occupational health problems prevail in the developing countries. In developing countries where workers work under exploitive condition with low income and unhealthy environment, their working condition influence the socio-economic status, health status and living environment of their dependent. In the absence of adequate provision for the protection of workers, their health became serious issue now a day (Barten and et al. 1996).

The basic problem of the cottage industry workers lies in the environment in which they live. The matrix created by socio-economic and political factors in a given biological and physical context constitutes the environment (Qadeer 2011).

Benavides (1992) argues that most small scale industries do not have a significant impact on the environment. On the contrary it can be argued that these industries do, in fact make a significant contribution in environmental contamination at local level i.e. in the neighbourhood of small scale industries. Such contamination can have a serious impact upon the state of health of the people living in these neighbourhoods (Cited by Barten, 1996).

According to European Industrial Relation Dictionary (2011), working condition refers to the working environment and aspects of an employee's terms and conditions of employment. This covers such matters as: the organisation of work, work activities, training, skill, health safety and well-being; and work time and work life balance. The relevant information based on field survey about work condition of the workers like nature of work place, working hours, nature of work, mode of payment and seasonal allowance are discussed.

Field survey regarding the work conditions of worker reveals some astonishing facts. Data on the type of house reveals that more than 60 percent workers live in the thatched and jhuggis. As far as handloom weavers are concerned, 100 percent are living in brick and concrete house because of having their ancestor's house. Majority of rice mill and flour grinding workers dwell in wood/jhuggis because they can afford to live in small houses only (Table.2). whereas 24.46 percent use for residential and industrial purpose both. About 5.44 percent workers use their house for residential, industrial and commercial purpose together. Multipurpose houses create congestion and pollution which make the workers more vulnerable for various health hazards.

Table 2. Work Conditions of the Sampled Workers in Ambedkarnagar District

Work Conditions		Percentage
Type of House	Brick /concrete	36.19
	Mud/thatched	19.84
	Wood/jhuggis*	42.41
	Others	1.56
Use of House	Residential	70.10
	Residential &Industrial	24.46
	Residential, Industrial &Commercial	5.44
Nature of Work Place	Open space	18.67
	Congested	81.33
	Market	6.67
	Open Drainage	33.33
	Others	10.67
Working Hour (per day)	8-10	22.57
	10-12	77.43
Mode of Payment	Time Rate	41.48
	Piece Rate	58.52
Nature of Wages	Daily	35.8
	Weekly	36.36
	Monthly	27.84
Seasonal Allowances	Receiving	27.61
	Non-receiving	72.39

Source: Based on Field Survey, 2012
*Hut

Sometimes cottage industry workers use their house for multi-purpose i.e. residential and industrial, residential and commercial and residential, industrial and commercial together when production is done on household level. Table.2 explains that majority of the workers (70.10 percent) use their houses only for residential purpose

The work environment in all the industry is not very much suited to the workers. Majority of them work in congested area where garbage and open drainage are found. It is observed from field survey that majority of the workers work in unhealthy surroundings because of open drainage, which causes spreading of diseases (Table 2).

Present study also reveals the working hours of cottage industry workers per day which is shown by Table.2 It is apparent from the table that about 77.43 per cent cottage industry workers work for 10-12 hours per day followed by 22.57 per cent work for 8-10 hour per day. Data reveals that in all the industry, workers are forced to work for long working hours i.e. more than 10 hours per day.

Data from the field survey reveals that about 68.48 per cent cottage industry workers get payment in cash while about 31.52 per cent workers do not receive payment because these workers are either family member or relatives. It is evident from the Table.2 that both methods i.e. the time rate and piece rate, are used for wage payment in the cottage industries of Ambedkarnagar district. About 58.52 per cent workers get their wage on piece rate and 41.48 per cent of workers paid on time rate basis. It is normally perceived that where the quality of product matter most, time rate mode of payment is better option whereas in term of quantity, most preferred mode of payment is piece rated. There is tree type of wage system prevails in Ambedkarnagar district. Data shows that 35.8per cent workers are daily wagers, 36.36 per cent weekly wagers and 27.84 per cent receive wage as monthly basis. Data in the table further reveals percentage distribution of workers according to seasonal allowances. According to the response of workers regarding seasonal allowance about 72.39 percent are not receiving any seasonal allowances whereas only 27.61 percent workers are receiving seasonal allowances occasionally.

MAJOR HEALTH PROBLEMS OF UNORGANISED INDUSTRIAL SECTOR WORKERS: AN ANALYSIS

Health is a dynamic concept embracing biological and social dimensions of well being. Table.3 shows percentage distribution of workers according to their responses either having health problem or not. Data analysis on health issues reveals that about 75.72 per cent workers don't have any health problems while 24.28 per cent reported about various health problems. The major health problems have been reported by workers of rice mill, flour grinding, handloom weaving, carpentry and spice grinding only. The association between different categories of industries and various health problems shows that problem of respiratory and muscular are frequently reported in rice mill, flour grinding and spice grinding workers as these industries are associated with dust problem and long working hours. Poor ventilation is a basic problem in these industries. During the process of grinding, large amount of dust produce and accumulate in the work place environment because of poor ventilation, hence workers get exposed to excessive amount of dust which leads to respiratory problem due to long time continuous exposure. With reference to the weavers skin diseases are reported more due to use of dye in the weaving material which causes itching (Table.3).

The fact that the problems of stress and sleep pervade in all category of industrial workers, the consequence of industrial environment are brought into sharp focus. Psychological stress caused by time and work pressure, have been associated with sleep disturbances. Majority of the workers in the cottage industry are daily wagers and living in poor socio economic condition so they are compelled to work for more than 10 hours, this lead to adverse psychological effects.

The data in Table.3 shows that back pain and shoulder pain are major physical problems found in practically all the categories of industries. The problem may have arisen due to posture, since most industries required constant standing posture and long working hours.

SPATIAL PATTERN OF SOCIO-ECONOMIC STATUS AND HEALTH STATUS

The relationship between socio-economic status of individual and their health is well documented in the international epidemiological, economic and social literature and from a variety of perspectives (Cortinovis et al. 1993; Durkin et al. 1994; Krieger et al. 1997; Robert, 1999; Lynch and Kaplan 2000; Kawachi et al 2002;

Table 3. Industry-wise Percentage Distribution of Workers according to Health Problems

Health Status		Rice mill	Flour grinding	Handloom weaving	Carpentry	Spice grinding	Total
Health Problems	Yes	21.33	24.20	60.00	3.03	33.33	24.28
	No	78.67	75.80	40.00	96.97	66.67	75.72
Nature of Health Problems	Skin	–	5.56	11.11	–	–	16.67
	Respiratory	5.56	16.67	5.56	–	16.67	44.44
	Muscular	–	11.11	5.56	5.56	11.11	33.33
	Stress& sleep	5.56	27.78	33.33	5.56	22.11	94.44
Discomfort in Body Parts	Back	–	11.11	27.78	–	11.11	50.00
	Neck	–	16.67	11.11	5.56	11.11	44.44
	Shoulder	5.56	22.22	16.67	–	22.22	66.67
	Others	–	22.22	5.56	5.56	5.56	38.89

Source: Based on Field Survey, 2012

Note: Multi-response Table

Oakes and Rossi 2003) Figure.1 depicts the regional variation in health status of worker's population. The composite mean Z-score varies from -0.91 to 1.30 score. These ranges of variation may be grouped into three categories i.e. high (above 0.41 score), medium (-0.41 to 0.41 score) and low (below -0.41 score). High level of health condition is found in Tanda, Akbarpur and Jalalpur because the workers in these blocks have health facility and also have accessibility to health care services. Three blocks fall in the category of medium level. These blocks are Bhiti, Katehri and Baskhari. Low level (below -0.41 score) of health condition is observed in Jahangirganj, Baskhari and Ramnagar.

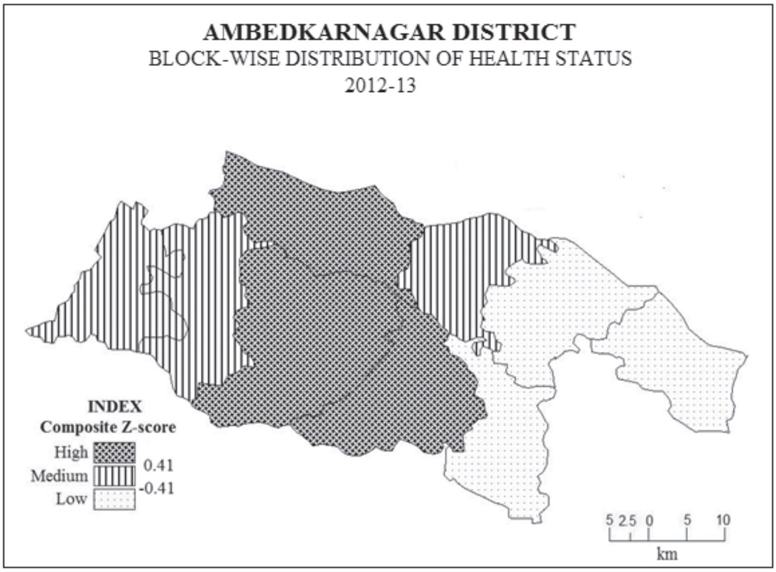


Fig. 1. Spatial variations in health status of worker's population

To measure socio-economic status, 28 variables have taken from different socio-economic parameter such as education, income, wealth, employment, health, demographic characteristics, and housing (Appendix I). These indicators depict more or less similar pattern of socio-economic condition in the district. It is decided to analyse the spatial pattern of socio-economic condition and therefore, all the concept are combined together. This means that an average index of socio-economic condition should be calculated with proper weightage of each index to give a composite index. The Z-score technique has been applied for this task. All data have been arranged in descending order and standardised to zero mean for interpretation. The positive value relating to the district's score show higher socio-economic status and negative value indicate low socio-economic condition. For this analysis, socio-economic conditions have been considered to be the function of 28 variables. Figure 2 reveals spatial pattern of socio-economic status related to worker's population. High grade of socio-economic condition is observed in Tanda, Akbarpur and Jalalpur (above 0.38 score) block because of development of cottage industry which leads to employment opportunity, high per capita income and high educational level. There are four blocks i.e. Katehri and Jahangirganj having composite mean Z-score between -0.38 to 0.38 score and come under the medium grade category of socio-economic status. Low grade is observed in Baskhari, Ramnagar and Bhiyaon and Bhiti (below -0.38 score).

The present analysis thus established the existence of regional variation in the level of socio-economic conditions among the blocks of the Ambedkarnagar district. Level of socio-economic condition varies substantially across the blocks of the district such as a variation caused by the variation of social and economic factors like employment, wealth, income, housing, family structure, educational level, health status etc. Although the present study could be cover all the variable associated with the socio-economic status.

RELATIONSHIP BETWEEN HEALTH STATUS AND SOCIO-ECONOMIC STATUS

The interrelationship between health status of worker's population and socio-economic status is shown in Figure 3 and it reveals that three blocks of the district fall under the high grade (above 0.44 score) of health status and also have high level (above 0.38 score) of socio-economic status. Three blocks experienced medium level (-0.41 to 0.41 score) of health status out of which only one block (Katehri) comes under the medium level (-0.38 to 0.38 score) of socio-economic status and remaining two blocks (Bhiti and Baskhari) have low grade (below -0.38 score) socio-economic status. The grade of low level (below -0.41 score) of health status is observed in the blocks of Ramnagar, Jahangirganj and Bhiyaon out of which Ramnagar and Bhiyaon blocks come under the category of low socio-economic status (below -0.38 score) while Jahangirganj block observed medium level of socio-economic status.

CONCLUSION

Occupational health is comprised of measures for protecting the workers against any health hazards arising out their work or conditions under which it is carried on. The industrial environment, prevailing today is far from conducive to generate a sense of happiness among the people who work within this environment. The various industrial processes and workplace environment create conditions that led to varying health problems in different industries as reflected in the physical and mental disorders afflicting this population. Although the exact occupational diseases could not be identified during this study, the ailments described by the respondents give sufficient indication of the nature of health problems that are being encountered.

The foregoing analysis throws light on the fact that there is a strong positive link between the socio-economic conditions, work conditions and resultant health problems of workers in unorganized sector. The result shows that health status of the workers is unsatisfactory. The majority of

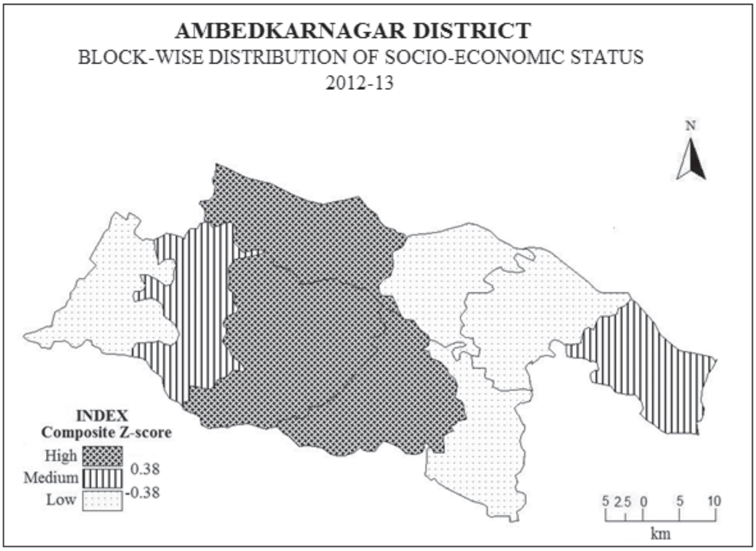


Fig. 2. Spatial pattern of socio-economic status related to worker's population

them were suffering from possible work related health problems i.e. respiratory, body discomfort and sleep disturbances.

The concept of general awareness about occupational safety and occupational and environmental hazards is not spread forward in the society towards the poor working conditions; it resulted in the deteriorating health conditions of Indian labour. There is an urgent need to introduce a legally binding mechanism for occupational health with the creation of an appropriate authority to supervise its implementation and enforcement at district level. This will help to ensure a uniform standard of occupational health care at all levels ensuring workers efficiency and well-being. There should be a strong provision of occupational health services, carrying out activities in the work place in the aim of protecting and promoting worker's safety, health and well-being as well as improving their working conditions and environment.

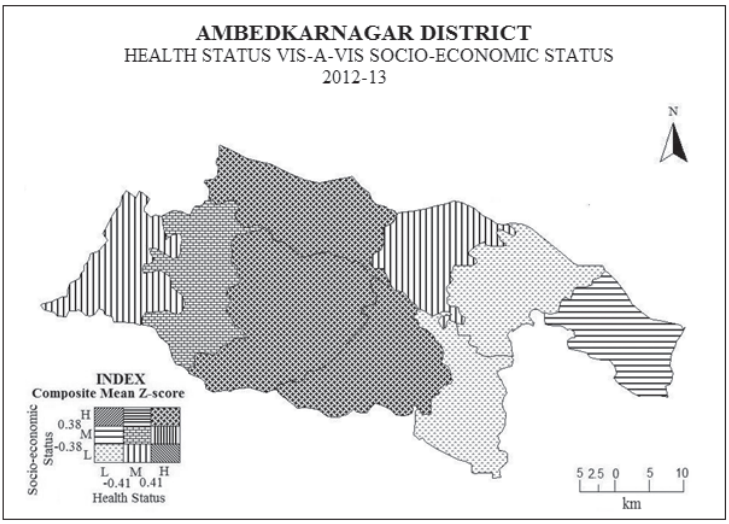


Fig. 3. The interrelationship between health status and socio-economic status of worker's population

Appendix I. Block-wise Distribution of Z-score of the Workers in Ambedkarnagar District

Name of Block	Demographic Characteristics	Educational Level	Economic Status	Housing Condition	Health Status	Socio-economic Status
Tanda	0.56	0.60	0.89	1.22	0.84	0.79
Akbarpur	0.78	1.81	1.09	1.10	1.30	1.23
Jalalpur	0.74	0.63	0.60	1.50	0.95	0.85
Baskhari	-0.97	-0.47	-0.72	-0.85	-0.35	-0.64
Ramnagar	-0.76	-0.66	-0.46	-0.92	-0.91	-0.69
Jahangirganj	-0.38	-0.21	0.21	-0.06	-0.43	-0.15
Katehri	0.18	-0.22	-0.08	-0.59	-0.16	-0.21
Bhiti	0.21	-0.48	-0.60	-0.67	-0.38	-0.42
Bhiyaon	-0.34	-1.00	-0.92	-0.71	-0.86	-0.77

Source: Based on Field Survey, 2012

REFERENCES

Anjum, M, and U.T. (2012) Health Status of Cottage Industry Workers in Ambedkarnagar District. IOSR Journal of Humanities and Social science, Vol.5, Issue .2, pp. 29- 32.

Baiq, L., Rasheed, S., and Zameer, M. (2005). Health and safety measures available for young labourers in the cottage industries of Karachi. Journal Coll Physicians Surg Pak, 15(6), pp. 7-10.

Banerji, N. (1985). Women workers in unorganised sector. Hyderabad: Sangam book.

Barten, F., Fustukian, S. and Haan, S. (1996). The occupational Health Needs of Workers: The Need for a New International Approach. Social Justice, 23(4), pp. 152-163.

Benavides, L. (1992). Hazardous waste management for small scale and cottage industries in developing countries. Paper presented in the international workshop on planning for sustainable urban development – cities and natural resource system in developing countries, Cardiff (13-17 July)

Census of India. (2001). District Census Handbook. Series-10, Part XII-A&B.

Chamila, T. (2013). Multiple voices, multiple realities: Female industrial workers' health in Sri Laka. Norwegian Journal of Geography, 57(3), pp. 154-163. DOI: 10.1080/00291950310002134

Cortinovis, I., Vella V. and Ndiku. J. (1993). Construction of a socio-economic index to facilitate analysis of health data in developing countries. Social Science and Medicine, 36(8), pp. 1087-1097.

Durkin, M., Islam S., Hasan Z., and Zaman S. (1994). Measures of Socio-economic status for child health research: Comparative result from Bangladesh and Pakistan. Social Science and Medicine. 38(9), pp. 1289-1297.

Hussain, A. (2007). Geography and Health. New Delhi: Mahaveer &Sons.

International Labour Organisation. (2013). [online] Available at: http://www.ilo.org/global/research/global-reports/global-employment-trends/2013/lang--en/index.htm

Jadab, K. (2012). Occupational health hazards and safety management for industrial workers. Odisha Review, October, pp. 64-69.

John, A. (1919). Health problems of industrial workers. Annals of the American Academy of Political and Social Series, 18A, Reconstruction labour policy, pp. 130-136.

James, S., James, A., Lawrence, R. and Anthony, J. (1979). Occupational stress and health among factory workers. Journal of Health and Social Behaviour, 20(2), pp. 139-160.

Kawachi, I., Subramanian S. and N. Almeida Filho (2002). A glossary for health inequalities. Journal of Epidemiology and Community Health, 56(9), pp. 647-652.

Krieger, N., Willains D. and Moss N. (1997). Measuring social class in public health research: Concept, methodologies and guidelines. Annual Review of Public Health, 18, pp. 341-378.

Lynch, J. and Kaplan G. (2000). Socio-economic position. In L.F. Berkman and I. Kawachi (eds.). Social Epidemiology (Oxford University Press), pp. 13-35.

Nalini, B. (2009). Work condition and health status in unorganised sector: A gender-based study. New Delhi: Serials Publications.

Oakes, J., and Rossi P. (2003). The measurement of SES in Health: Current practice and steps toward a new approach. Social Science and Medicine, 56(4), pp. 769-784.

Papola, T. (1980). Informal sector: Concept and policy. Economic and Political Weekly. 15(18). Pp. 817-824.

Qadeer, I. (2011). Public health in India: Critical reflections. New Delhi: Daanish Publication.

Robert, S. (1999). Socio-economic position and health: the independent contribution of community socio-economic context. Annual Review of Sociology, 25, pp. 489-516.

Rongo,L., Barten, F., Msamanga, GI, Heederik, D. and Dolmans, W. (2004). Occupational exposure and health problems in small-scale industry workers in Dar es Salaam, Tanzania: A situation analysis. Occupational Medicine, 54(1), pp. 42-56.

Saha, Tushar, K., Dasgupta, A., Butt, A., and Chattopadhyay (2010). Health status of workers engaged in small-scale garment industry: How healthy are they?. Indian Journal of Community Medicine, 35(1), pp. 179-182.

The European Industrial Relation Dictionary. Working Conditions. [online] Available at: https://www.eurofound.europa.eu/efemiredictionary/working-conditions

World Health Organization (1997). Occupational health: The work place. [online] Available at: http://www.who.int/topics/occupational_health/en/

Received on June 15th, 2017 Accepted on August 10th, 2017

Dr. Mahvish Anjum is working as a Post Doctoral Fellow in the Department of Geography, Aligarh Muslim University. She has received her graduation, post graduation and Ph. D. degrees in Geography at Aligarh Muslim University, Aligarh. Her interest areas concentrate on Health geography, Industrial and social geography. Dr. Anjum is the author of over a dozen research papers in International reputed journals and two books in the areas of her competence. She has also served as reviewer for the journal of Sage publications and others. She was received UGC-Junior Research Fellow Award and Travel Grants Award for Abroad. In addition she has attended a training course Geographic Information System at Cadi Ayyad University, Morocco. She has presented papers in 20 national and international conferences. She has completed two projects to her credit.

Dr. Nizamuddin Kha is Honorary Professor in Department of Geography at Aligarh Muslim University. He has an experience of 20 years in teaching and research. Dr. Khan's research interests are in agricultural marketing, rural marketing, and political geography. He has published 90 research papers in various national and international reputed journals. He has also completed five major research projects sponsored by ICSAR, ICSSR, UGC New Delhi and UPCST, Lucknow in the field of livestock husbandry and agricultural marketing. Prof. Khan has also authored nine books. He is the recipient of various national and International scholarships and awards.

INSTRUCTIONS FOR AUTHORS CONTRIBUTING TO "GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY"

AIMS AND SCOPE OF THE JOURNAL

The scientific English language journal 'GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY' aims at informing and covering the results of research and global achievements in the sphere of geography, environmental conservation and sustainable development in the changing world. Publications of the journal are aimed at foreign and Russian scientists – geographers, ecologists, specialists in environmental conservation, natural resource use, education for sustainable development, GIS technology, cartography, social and political geography etc. Publications that are interdisciplinary, theoretical and methodological are particularly welcome, as well as those dealing with field studies in the sphere of environmental science.

Among the main thematic sections of the journal there are basics of geography and environmental science; fundamentals of sustainable development; environmental management; environment and natural resources; human (economic and social) geography; global and regional environmental and climate change; environmental regional planning; sustainable regional development; applied geographical and environmental studies; geo-informatics and environmental mapping; oil and gas exploration and environmental problems; nature conservation and biodiversity; environment and health; education for sustainable development.

GENERAL GUIDELINES

1. Authors are encouraged to submit high-quality, original work: scientific papers according to the scope of the Journal, reviews (only solicited) and brief articles.

2. Papers are accepted in English. Either British or American English spelling and punctuation may be used. Papers in French are accepted under the decision of the Editorial Board.

3. All authors of an article are asked to indicate their names (with one fore **name** in full for each author, other forenames being given as initials followed by the surname) and the name and full postal address (including postal code) of the **establishment(s)** where the work was done. If there is more than one institution involved in the work, authors' names should be linked to the appropriate institutions by the use of 1, 2, 3 etc superscript. **Telephone and fax numbers and e-mail addresses** of the authors could be published as well. One author should be identified as a **Corresponding Author.** The e-mail address of the corresponding author will be published, unless requested otherwise.

4. The GES Journal style is to include information about the author(s) of an article. Therefore we encourage the authors to submit their photos and short CVs.

5. The optimum size of a manuscript is about 3 000 – 5 000 words. Under the decision (or request) of the Editorial Board methodological and problem articles or reviews up to 8 000 – 10 000 words long can be accepted.

6. To facilitate the editorial assessment and reviewing process authors should submit "full" electronic version of their manuscript with embedded figures of "screen" quality as a **.pdf file.**

7. We encourage authors to list three potential expert reviewers in their field. The Editorial Board will view these names as suggestions only. All papers are reviewed by at least two reviewers selected from names suggested by authors, a list of reviewers maintained by GES, and other experts identified by the associate editors. Names of the selected reviewers are not disclosed to authors. The reviewers' comments are sent to authors for consideration.

MANUSCRIPT PREPARATION

Before preparing papers, authors should consult a current issue of the journal at http://ges.rgo.ru/jour/issue/current to make themselves familiar with the general format, layout of tables, citation of references etc.

1. Manuscript should be compiled in the following **order**: authors names; authors affiliations and contacts; title; abstract; key words; main text; acknowledgments; appendices (as appropriate); references; authors (brief CV and photo)

2. The **title** should be concise but informative to the general reader. The **abstract** should briefly summarize, in one paragraph (up to 1,500 characters), the general problem and objectives, the results obtained, and the implications. Up to six **keywords**, of which at least three do not appear in the title, should be provided.

3. The **main body** of the paper should be divided into: (a) **introduction**; (b) **materials and methods**; (c) **results**; (d) **discussion**; (e) **conclusion**; (f) **acknowledgements**; (g) **numbered references**. It is often an advantage to combine (c) and (d) with gains of conciseness and clarity. The next-level subdivisions are possible for (c) and (d) sections or their combination.

4. All **figures** (including photos of the authors) are required to be submitted as separate files in original formats (CorelDraw, Adobe Photoshop, Adobe Illustrator). Resolution of raster images should be not less than 300 dpi. Please number all figures (graphs, charts, photographs, and illustrations) in the order of their citation in the text. Composite figures should be labeled A, B, C, etc. Figure captions should be submitted as a separate file.

5. **Tables** should be numbered consecutively and include a brief title followed by up to several lines of explanation (if necessary). Parameters being measured, with units if appropriate, should be clearly indicated in the column headings. Each table should be submitted as a separate file in original format (MS Word, Excel, etc.).

6. Whenever possible, total number of **references** should not exceed 25-30. Each entry must have at least one corresponding reference in the text. In the text the surname of the author and the year of publication of the reference should be given in square brackets, i.e. [Author1, Author2, 2008]. Two or more references by the same author(s) published in the same year should be differentiated by letters a, b, c etc. For references with more than two authors, text citations should be shortened to the first name followed by et al.

7. **References** must be listed in alphabetical order at the end of the paper and numbered with Arabic numbers. References to the same author(s) should be in chronological order. Original languages other than English should be indicated in the end of the reference, e.g. (in Russian) etc.

Journal references should include: author(s) surname(s) and initials; year of publication (in brackets); article title; journal title; volume number and page numbers.

References to books should include: author(s) surname(s) and initials; year of publication (in brackets); book title; name of the publisher and place of publication.

References to multi-author works should include after the year of publication: chapter title; «In:» followed by book title; initials and name(s) of editor(s) in brackets; volume number and pages; name of the publisher and place of publication.

8. Authors must adhere to SI units. Units are not italicised.

9. When using a word which is or is asserted to be a proprietary term or trade mark, authors must use the symbol ® or TM.

10. As Instructions for Authors are subjected to changes, please see the latest issue at http://ges.rgo.ru/jour/issue/current

MANUSCRIPT SUBMISSION

Authors are encouraged to submit their manuscripts on-line using the GES Journal web-site http://ges.rgo.ru/index (after registration)

SOCIALLY SCIENTIFIC MAGAZINE "GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY"

No. 03 (v. 10) 2017

FOUNDERS OF THE MAGAZINE: Russian Geographical Society, Faculty of Geography, Lomonosov Moscow State University and Institute of Geography of the Russian Academy of Sciences

The magazine is published with financial support of the Russian Geographical Society.

The magazine is registered in Federal service on supervision of observance of the legislation in sphere of mass communications and protection of a cultural heritage. The certificate of registration: ПИ № ФС77-67752, 2016, December 21.

EDITORIAL OFFICE
Lomonosov Moscow State University
Moscow 119991 Russia
Leninskie Gory,
Faculty of Geography, 1806a
Phone 7-495-9391552
Fax 7-495-9391552
E-mail: GES@rgo.ru
www.ges.rgo.ru

DESIGN & PRINTING
Agency «CONNECT»
Moscow, 117452,
Artekovskaya str., 9, korp. 1
Phone: +7 (495) 955-91-53
E-mail: info@connect-adv.ru

Sent into print 26.09.2017
Order N gi317

Format 70 ½ 100 cm/16
8,37 p. sh.
Digital print
Circulation 150 ex.