ACTA UNIVERSITATIS CAROLINAE

# AUC **GEOGRAPHICA**

**52**
**2/2017**

CHARLES UNIVERSITY • KAROLINUM PRESS • 2017

ISSN 0300-5402 (Print)
ISSN 2336-1980 (Online)

# CONTENTS

# EVALUATION OF THE INFLUENCE OF MOUNTAIN PEAT BOGS RESTORATION MEASURES ON THE GROUNDWATER LEVEL: CASE STUDY ROKYTKA PEAT BOG, THE ŠUMAVA MTS., CZECH REPUBLIC

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**ABSTRACT**

The paper evaluates measures taken to restore mountain Peat Bogs and their effect on hydrological regime, with the main focus on groundwater levels. The level of groundwater is a key factor in maintaining the character of mountain Peat Bogs and the main objective of restoration is to increase and stabilize the groundwater level in disturbed Peat Bogs. At the same time, the paper provides a complex overview of the topic, which is being often discussed nowadays, mostly due to a big retention potential of mountain Peat Bogs. The paper is based on detailed measurements of groundwater levels in a selected experimental drainage ditch in the catchment of the Rokytka stream. Basic statistical characteristics, the equation of Penman-Montheit or antecedent precipitation index were used to show the dependence of groundwater level on precipitation or evapotranspiration. The results show a positive influence of the restoration measures on Peat Bogs. In this case it has been confirmed that restoration measures cause increase of groundwater level and decrease its fluctuation in the Peat Bog.

**Keywords:** Peat Bog, groundwater level, the Šumava Mts., Peat Bog restoration

Received 27 August 2016; Accepted 1 June 2017; Published online 19 July 2017

## 1. Introduction

In the context of occurrence of hydrological extremes (floods, droughts), the increase of retention ability of headwater areas has recently become a fundamental question. The headwater area of the Otava River is characterized by a great amount of Peat Bog complexes, whose hydrological regime has not been completely uncovered yet, in spite of numerous analyses (Janský and Kocum 2008). The most recent studies emphasize that the occurrence of Peat Bogs in a catchment increases the extremity of flow (Holden et al. 2011; Holden et al. 2001; Ferda et al. 1971; Čurda et al. 2011).

The increase of a discharge in streams which have been restored is particularly significant at the Šumava Mts. catchments (Čurda et al. 2011). However, Peat Bog restoration measures could also have a negative effect on runoff process during flood events (Holden et al. 2011).

Restoration measures contribute greatly to a decrease of fluctuation of drainage ditches in the cases of mean and low flow. However, in the case of a higher water content caused by intensive precipitation, the barriers, which retain water in a catchment, might have negative effects on area retention capacity. After an excess of retention capacity of these barriers, an intense and rapid increase of flow follows, reaching a higher extremity (Čurda et al. 2011). Organic soils or other waterlogged areas saturated with water can then function as an outflow accelerator. Despite the fact that organic soils have a great retention capacity for water, releasing it gradually to the streams, their retention capacity is not applied in the case of water saturation (Šefrna 2004).

The depth of groundwater in organic soils is a very important factor for Peat Bog ecosystems. In an undisturbed Peat Bog, groundwater is situated very close to surface for most of the year and water fluctuation is largely limited (Holden et al. 2001). The changes in groundwater level concern mainly Acrotelm, which is characterized by higher porosity. Lower situated Catotelm includes more decomposed organic material with smaller pores and lower hydraulic conductivity, so the water movement is extremely limited there (Rizzuti et al. 2004). The combination of the characteristics of Acrotelm and Catotelm thus makes Peat Bogs a significant water reservoir with a unique hydrological regime in the area (Holden et al. 2011). Dynamics of groundwater level is also significant during a low precipitation period. Peat Bog reacts very fast. The rate of groundwater level changes can reach several centimeters per day (Vlček et al. 2012). The main factors influencing groundwater level in Peat Bogs are precipitation, evapotranspiration, topography and, in a local scale, also peat porosity and hydraulic conductivity (Allott et al. 2009).

The main changes in the Šumava Mts. Peat Bogs have been caused by efforts of draining and drying. Peat Bogs have been traditionally drained for the purpose of peat exploitation, agricultural land cultivation, or increase in wood exploitation in waterlogged forest areas. Nevertheless, the extent of surface drains was already considerable at the turn of the 19th and the 20th century. However,

https://doi.org/10.14712/23361980.2017.11
Doležal, T. – Vlček, L. – Kocum, J. – Janský, B. (2017): Evaluation of the influence of mountain peat bogs restoration measures on the groundwater level: case study Rokytka peat bog, the Šumava Mts., Czech Republic
AUC Geographica, 52, No. 2, pp. 141–150

the major period of drainage digging was in the 70s and 80s of the 20th century. Nowaday, the drainage systems are still visible. Stocktaking researches have displayed that drainage has affected almost 70% of Peat Bogs in the Šumava Mts. (Bufková 2013). The open system of drains causes especially: fast surface flow, steeper culmination, and higher fluctuations of groundwater level (Ballard et al. 2011). Performed restorations can improve these aspects and consequently increase the groundwater level by several centimeters in a year (Worrall et al. 2007). A research from Schachtenfilz in the Bavarian Forest has confirmed that restoration measures increased groundwater level and decreased its fluctuation (Bufková 2013).

Since 1998 a complex restoration program has been implemented in the area of the National Park of Šumava (The Program of Restoration of Šumava Wetlands and Peat Bogs). The program is primarily aimed at a general improvement of disturbed water regime in the Peat Bog area (Bufková et al. 2010). A concept of so called "target water level" has been exercised during the restoration in the Šumava Mts. The method is based on determination of necessary water level, which is particular for each Peat Bog, eventually for their parts, and which is desirable to be achieved by restoration measures. The necessary water level can be described as a maximal tolerated decline of water in a ditch under the dam head, which is bearable for a given type of a Peat Bog (Bufková 2006). However, the increase of water level can be only observed few meters from a restoration because groundwater level is no longer influenced by the drainage system in a further distance from the drainage ditch (Wilson et al. 2011; Holden et al. 2011).

Peat Bogs are physically and ecologically adapted on the depth of groundwater level. The depth has a great significance for ecological niches of vegetative species and hence even for peat development (Kværner and Snilsberg 2011). The response of groundwater level on an exercised restoration is usually very fast; nevertheless, the changes in water chemism and consequent reactions of Peat Bog species are very slow. Peat Bog vegetative species are vulnerable and sudden changes of pH factor or changes in the amount of nutrients after exercising restoration can also have negative effects. Peat Bog restoration consequently includes stabilization and increase of groundwater level and a repeated habitation of the standpoint by Peat Bog species. It is thus important to limit the amount of water drain (Holden 2005).

However, there are still several problems, namely uncertain influence on water drainage ditch and water chemism, uncertain response species on water regime changes, and the price for restoration (Holden 2005).

The main aims of this paper are:

- to establish the influence of a drainage ditch on groundwater level in an experimental catchment;
- to determine dependence of groundwater level behavior on evapotranspiration and precipitation and its influence on groundwater level changes;
- to describe differences in groundwater levels near a functional drainage ditch and near a restored part of a drainage ditch (increased water level in the ditch due to a wooden dam).

## 2. Site description

The catchment of the Rokytka stream (Fig. 1) is located in the central part of the Šumava Mts. The whole complex of Rokytka Peat Bogs is placed on moderate slopes near the bottom of the Rokytka stream valley. The complex comprises several large and many small mountain Peat Bogs, which are surrounded by forest Peat Bogs, waterlogged pine stands, and minerotrophic sedge Peat Bogs (Bufková 2009). The total area of the Peat Bog is almost 250 ha. The depth of large Peat Bogs is about 5 m. Although in some locations, it can reach up to 7 m (Bufková and Spitzer 2008). Height relations of the catchment are consistent with the location of the central flat areas of the Šumava Mts. The altitude alters between 1089 and 1244 m a.s.l. The Rokytka catchment is rather flat in spite of its high altitude. The average gradient of slope is only 4°. Only exceptionally the gradient of slope reaches up to 10°, with the maximum of 12° (Jelínek 2009).

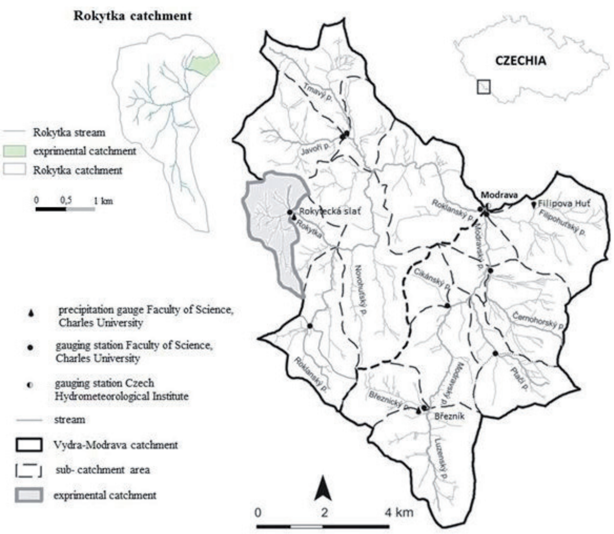


**Fig. 1** The catchment of the Vydra River with the positions of gauging stations of the Czech Hydrometeorological Institute and automatic level gauges and precipitation gauges of the Faculty of Science, Charles University. The Rokytka stream catchment and the monitored experimental catchment is highlighted. Source: Kocum, Janský (2009).

The research of the Rokytka Peat Bog was focused on a selected experimental drainage ditch, which is located in the northern part of the catchment, at 1100 m a.s.l., and which drains an area of 0.14 km$^2$. The drainage ditch was partially dammed by small restoration dams; partially it was left functional, with a depth of 1 m.

In terms of soil cover, the soil region consists of entic Podzol, even of Rankers in steep slope areas (Šefrna 2004).

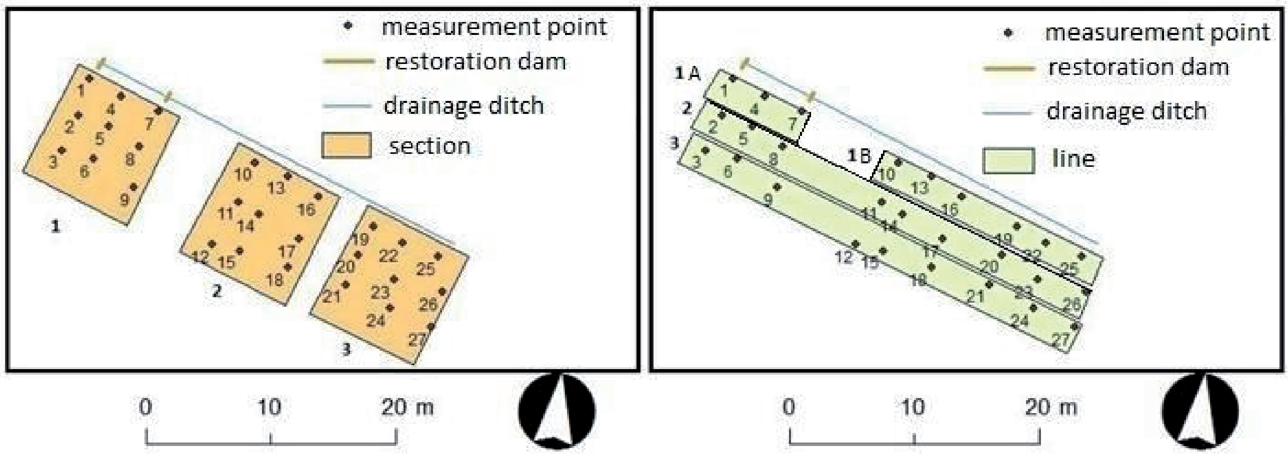


**Fig. 2** The scheme of particular measurements of groundwater level and of the segments where the groundwater level was measured.

The soil of the researched catchment is a typical example of soil of the Šumava Mts., where a vertical sequence of soil is typical. Organic soil only occurs in watersheds and at the bottom of the valley. The catchment of Rokytka is mostly covered by Histosols. A peaty Gley can be found in some parts of the stream floodplains. Gleys are represented only marginally. The monitored drainage ditch is located in the part of a Peat Bog with a prevailing occurrence of fibric organic soil. The total area of organic soils in the catchment is 0.87 km$^2$, which stands for 23% of the whole area (Vlček et al. 2012).

In the area of interest, there are two precipitation gauges with long data series. It is Březník (1150 m a.s.l.) and Modrava (1000 m a.s.l.). The annual precipitation in Březník alters between 1100 and 1300 mm. The long term average of annual precipitation from Modrava is 1100 mm (Kocum 2012).

The annual discharge minimum can be measured at the end of February (before the snow melting) or in September (at the end of summer, a dry period). Discharge maximum is generally in spring, when the snow melts. A significant fluctuation in the outflow can also be seen in the summer period, due to a higher frequency of intensive precipitation. However, this fact does not influence the average monthly discharge variability, which might be caused by short duration of precipitation (Kocum 2012).

The vegetation in the Rokytka catchment is formed by a relict plant community. Low grass with the growth of *Trichophorum caespitosum* can be found there, predominantly. It blends in a mosaic pattern with the hydrophilic vegetation of shallow oblong depressions and the edges of lakes. It is made of a mat of *Sphagnum cuspidatum* and *Sphagnum majus* with the growth of *Carex limosa* and *Scheuchzeria palustris*. One of the constituents of *Trichophorum caespitosum* are obvious, large, and cambered bults with reddish types of peat as *Sphagnum magellanicum*, *Sphagnum russowii* or *Sphagnum rubellum* (Bufková 2009). In the surroundings of the monitored drainage ditch, the herb vegetation is formed by *Vaccinium uliginosum*, *Empetrum nigrum* or *Andromeda polifoli*a are also plentifully represented here. Nevertheless, the most dominant is vegetation primarily *Pinus mugo*.

## 3. Methodology

Groundwater level measurements were implemented during the period from August 14, 2014 to October 31, 2014. The groundwater level was measured manually in tubes which were inserted into the peat to a depth of 1–1.5 m. The water levels were measured in lines which were copying parts of the drainage ditch and the distance between measurement points was 3 meters. Thus, a regular net with 27 groundwater level measurement points, placed in regular distances, was created. The groundwater level was measured from the surface. For this purpose, particular segments were created from the measuring areas and the groundwater levels were then compared with each other within the scope of the individual sections and lines (see Fig. 2). The line 1 was divided into part A and part B for better accuracy. Part A is located directly to restoration dams and part B is placed in area which is not affected of restoration measures. At the same time, tubes were located by a total station, so the exact location of measurement points is known and therefore maps and interpolations could be created. At each point, 28 values of groundwater level were measured. Further, particular level changes were statistically evaluated in the scope of individual sections and lines to better demonstrate the dependence of groundwater level fluctuation on the distance from a drainage ditch, or from restoration dams. Data of groundwater level from an automatic station in Rokytka Peat Bog were also used. Additionally an interpolation method "natural neighbor" was applied to obtain range information. At first, the whole dataset was analyzed by basic statistical characteristics and data testing. For distribution of measured values of groundwater level in various intervals box plots were used. Statistical characteristics variance, correlation coefficient and directive deviance were calculated. All the statistical

**Tab. 1** Statistical characteristics of groundwater level fluctuation in sections and lines.

| | line 1A | line 1B | line 2 | line 3 | section 1 | section 2 | section 3 |
|---|---|---|---|---|---|---|---|
| **Number of measured values** | 84 | 168 | 252 | 252 | 252 | 252 | 252 |
| **Average groundwater level (cm)** | 13.04 | 23.04 | 18.13 | 10.49 | 10.95 | 17.93 | 19.37 |
| **Medium (cm)** | 12.90 | 24.70 | 18.90 | 10,80 | 11.20 | 15.85 | 18.90 |
| **Minimum (cm)** | 0.10 | 7.50 | 2.30 | 0.10 | 0.00 | 6.30 | 4.80 |
| **Maximum(cm)** | 28.00 | 50.00 | 42.00 | 30.00 | 28.80 | 50.00 | 50.00 |
| **Variance** | 28.98 | 69.16 | 53.94 | 30.67 | 46.98 | 63.09 | 52.72 |
| **Directive deviation** | 5.39 | 8.31 | 7.34 | 5.54 | 6.85 | 7.94 | 7.26 |

procedures were calculated in a statistical software StatSoft Statistica.

Groundwater level fluctuation was put into context with particular significant factors of rainfall-runoff process. One of them is potential evapotranspiration (equation 1). In this research, Penman-Monteith equation was used for the determination of daily potential evapotranspiration. In this case, the daily potential evapotranspiration is calculated according to the following equation:

$$PET_0 = \frac{0.408 \cdot \Delta \cdot (Rn\text{-}G) + \gamma \cdot \dfrac{900}{T+273.16} \cdot u \cdot (e_s\text{-}e_a)}{\Delta + \gamma \cdot (1+0.34 \cdot u)} \quad (1)$$

where Δ represents the inclination of water vapor saturation curve in dependence on temperature [kPa °C$^{-1}$], *Rn* radiation balance [MJ m$^{-2}$ day$^{-1}$], *G* flow of heat into soil [MJ m$^{-2}$ day$^{-1}$], *Υ* psychometric constant [kPa °C$^{-1}$], *u* speed of wind [m s$^{-1}$], $(e_s - e_a)$ saturation deficit of air in elevation z [kPa], *T* average air temperature [°C] (Penman, 1948).

The antecedent precipitation index API (equation 2) is also applied in this paper. The index is used for determination of catchment saturation and it expresses the influence of precipitation which occurred in previous days to the given date. It thus demonstrates the ability of a catchment to absorb more precipitation. For the purpose of this paper, the API index was calculated for five previous days according to the following equation:

$$API = \sum 0.93^i \cdot P_i \quad (2)$$

where "*i*" stands for the number of the day counted back from the date, which API is counted for, *P* daily amount of precipitation, [mm] in the *i*-th day before the causal precipitation (Mishra and Singh 2003).

## 4. Results

### 4.1 Statistical evaluation of groundwater level fluctuation

When basic statistical characteristics were used, significant differences between the areas lying near restoration dams and those with the absence of restoration were ascertained. At first, statistical differences were tested in sections using analysis of variance ANOVA. Significant differences on the probability level ($p < 0.05$) were proven. The resulting coefficients were significantly higher than the critical value of the distribution (31.5 > 3). It means that high differences between data sets were detected. However, the analysis was not able to show where exactly the differences occurred. Due to this fact, a t-Test was used on the probability level ($p < 0.05$). The only significant difference was detected between section 1 and section 3. In other cases, the differences were not prominent.

In the case of lines, a uniquely high difference can be found in the biggest proximity of the drainage ditch (line 1A and 1B), Fig. 3. The difference between average groundwater levels in these two lines during a monitored period was 10 cm. The data from a distance of 6 m from the drainage ditch are very similar to line 1A from the location with restoration measures. Consequently, it can be presumed that in the distance of 6 m from restoration measures, the behavior of the groundwater level seems natural. The amplitude in the distance of 6 m from the drainage ditch was only 29.9 cm. It is very similar to line 1A which contains data from the area with restoration measures. A similar divergence can be seen during evaluation of particular sections. In the scope of section number 1 (Fig. 3), which is the closest one to the exercised restoration, it was proven that the groundwater level is less fluctuated and that it remains near the surface. In this section, the average groundwater level was 10.95 cm and the amplitude was 8 cm. On the contrary, in the furthest section, the average groundwater level, for the monitored period of time, was 19.37 cm and the amplitude reached up to 45.2 cm. Thus, in the proximity of restoration, the level of groundwater is located 8.42 cm higher on average.

In Table 1, statistical characteristics of groundwater level fluctuation in sections and lines are shown. For example, line 1B, which is the nearest to the drainage ditch without restoration measures, expresses the highest numbers in variance and in directive deviations. On the contrary, the furthest line 3 and line 1A with restoration measures have significantly lower values. When sections were compared, it was observed that section 1, which is the closest to restoration, disposes of the lowest numbers

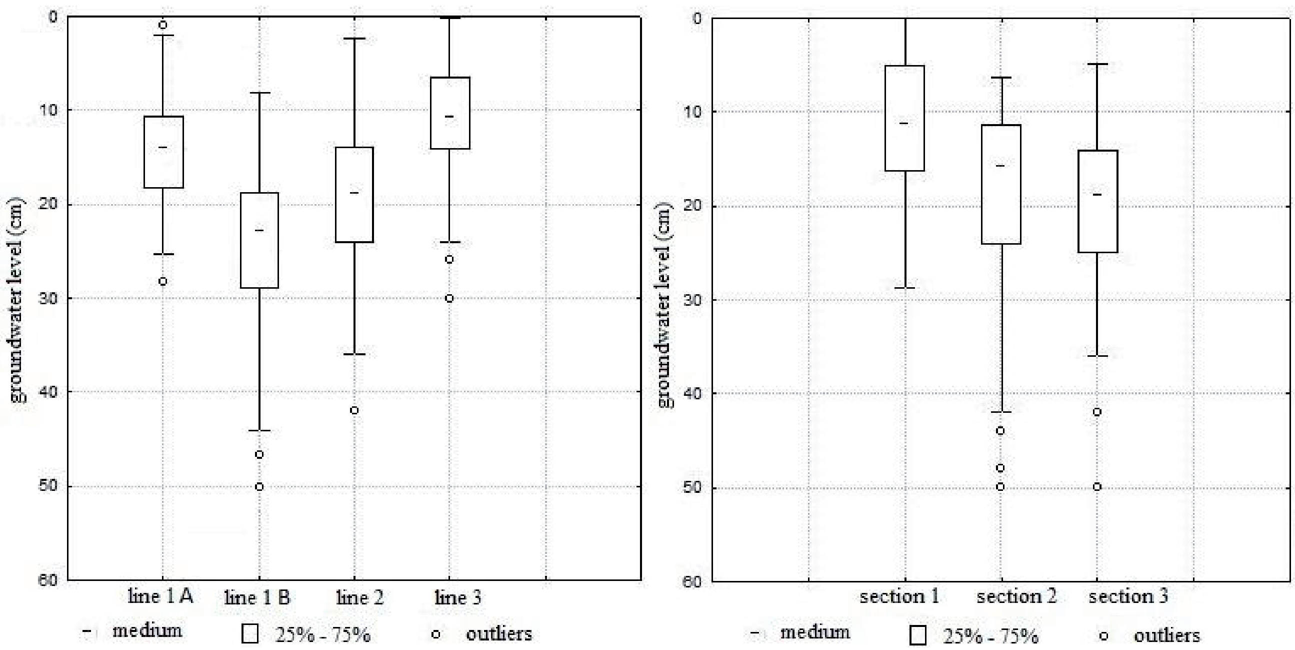


**Fig. 3** Groundwater level fluctuation in the scope of particular sections and lines.

in variance and in directive deviations. Further sections show expressively higher values which point to a positive influence of restoration measures on fluctuation and on groundwater level.

The highest groundwater level can be found at measuring points in the proximity of restoration. The above mentioned statement, that the higher the distance from the drainage ditch, the higher the groundwater level, is also confirmed here. Another important finding is that in the distance of 6 m from the drainage ditch, the drainage effect can no longer be seen.

## 4.2 The dependance of groundwater level on meteorological factors

In particular sections, the groundwater level fluctuation was compared to the difference between precipitation and evapotranspiration between measurements.

It was found that these two factors are the most essential ones for groundwater level. A dependence was visible in Fig. 4, moreover, with quite high coefficients of determination. The dependence was proven most significantly in the section located the closest to the drainage ditch. Consequently, a daily groundwater level fluctuation can be rather accurately estimated and explained with the regard of these two factors.

A few values of decrease of groundwater level were also observed when precipitation was higher than evapotranspiration. This fact could be caused by an interception. During a lower precipitation period, rainwater is probably intercepted by trees, which growth rather densely in the experimental area.

For the quantification of the dependence, coefficients of determination and other correlation coefficients were calculated. Correlation coefficients in Table 2 reach very high values. The dependence of groundwater level on precipitation and evapotranspiration is statistically significant in sections 1 and 3.

**Tab. 2** Correlation coefficients and determination coefficient in particular sections, mark * is statistical significant at probability level, $p < 0.05$.

| | **section 1** | **section 2** | **section 3** |
|---|---|---|---|
| **Coefficient of determination (level change; ET-precipitation)** | 0.869* | 0.770 | 0.842* |
| **Correlation coefficient (level change; ET-precipitation)** | 0.755* | 0.593 | 0.708* |
| **Correlation coefficient (average level; API)** | −0.532* | −0.306 | −0.511* |

The same approach was exercised at the automatic station at Rokytka Peat Bog. The difference is in the fact that the station is in a sufficient distance from the drainage ditch and therefore it is not influenced by melioration. It was revealed that the difference of precipitation and evapotranspiration describes the actual course of groundwater level more precisely (see Fig. 5). The moving average of the difference of precipitation and evapotranspiration follows precisely the process of groundwater level changes. The changes of groundwater level in an area with no human influence in Peat Bog can be expressed more precisely and its course corresponds better to meteorological factors.

## 4.3 Groundwater level fluctuation during chosen episodes

The variability of groundwater level is also an important factor. Two episodes have been selected for an evaluation. The first one, an episode of intensive precipitation

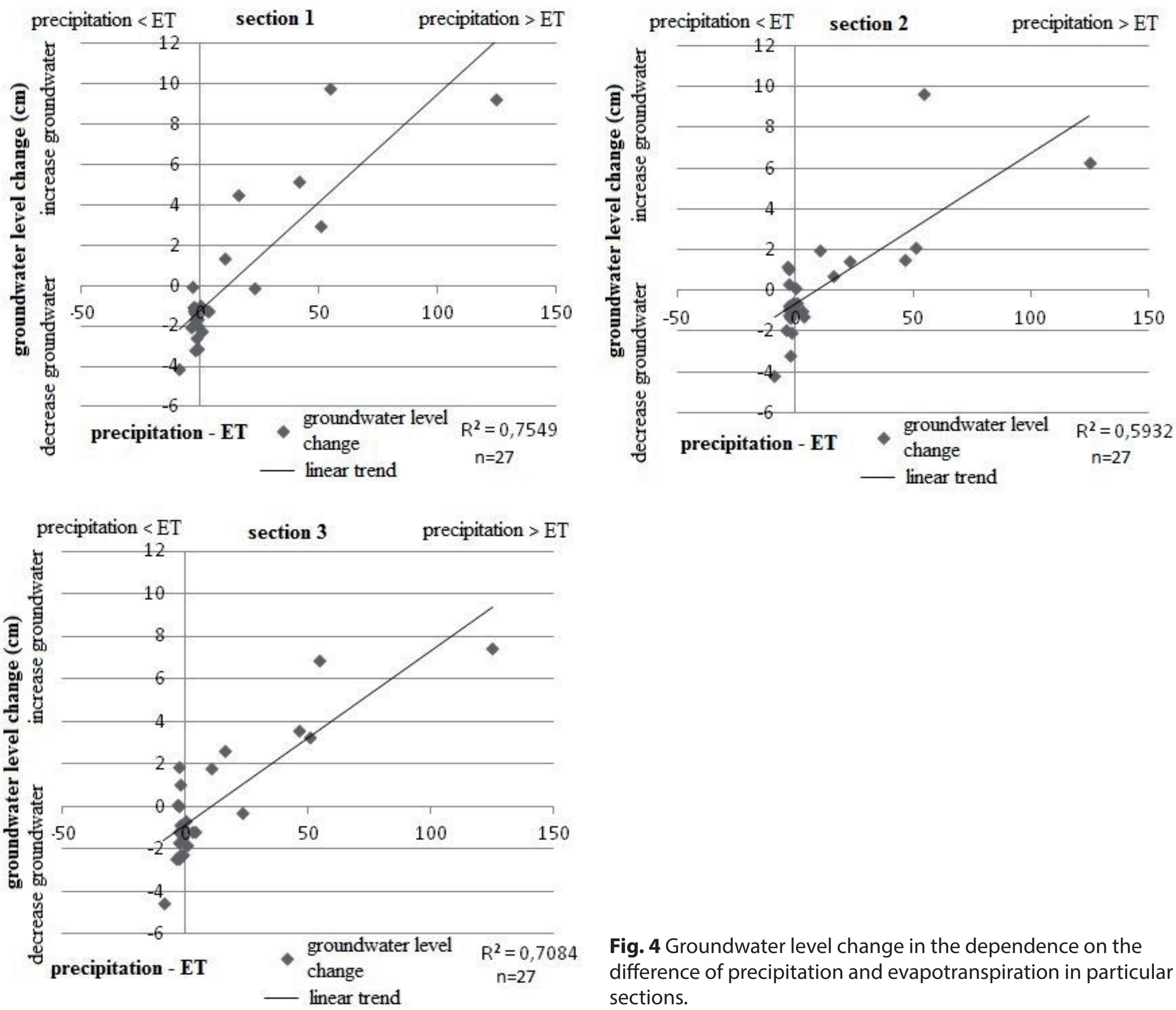


**Fig. 4** Groundwater level change in the dependence on the difference of precipitation and evapotranspiration in particular sections.

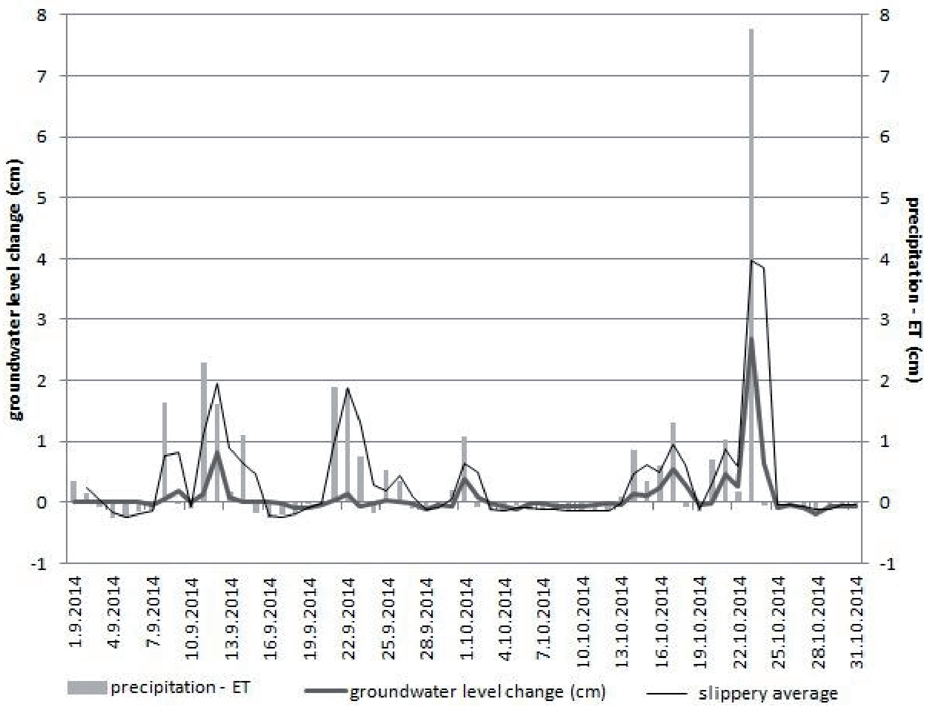


**Fig. 5** The fluctuation of daily average groundwater level in dependence on the difference of precipitation and evapotranspiration in Rokytka Peat Bog, from the September 1, 2014 to October 31, 2014. Source: Data from the automatic station of Faculty of Science, Charles University.

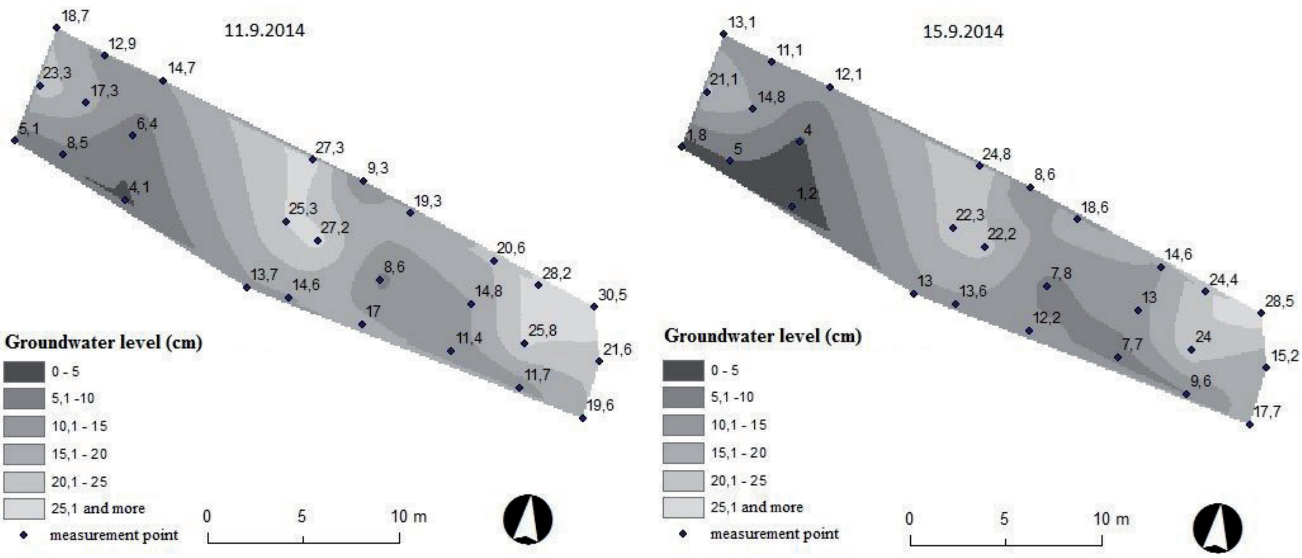


**Fig. 6** Changes of groundwater level during a selected episode of intensive precipitation between the September 11, 2014 and September 15, 2014. The given numbers in the graph represent measured groundwater level in centimeters on a given day.

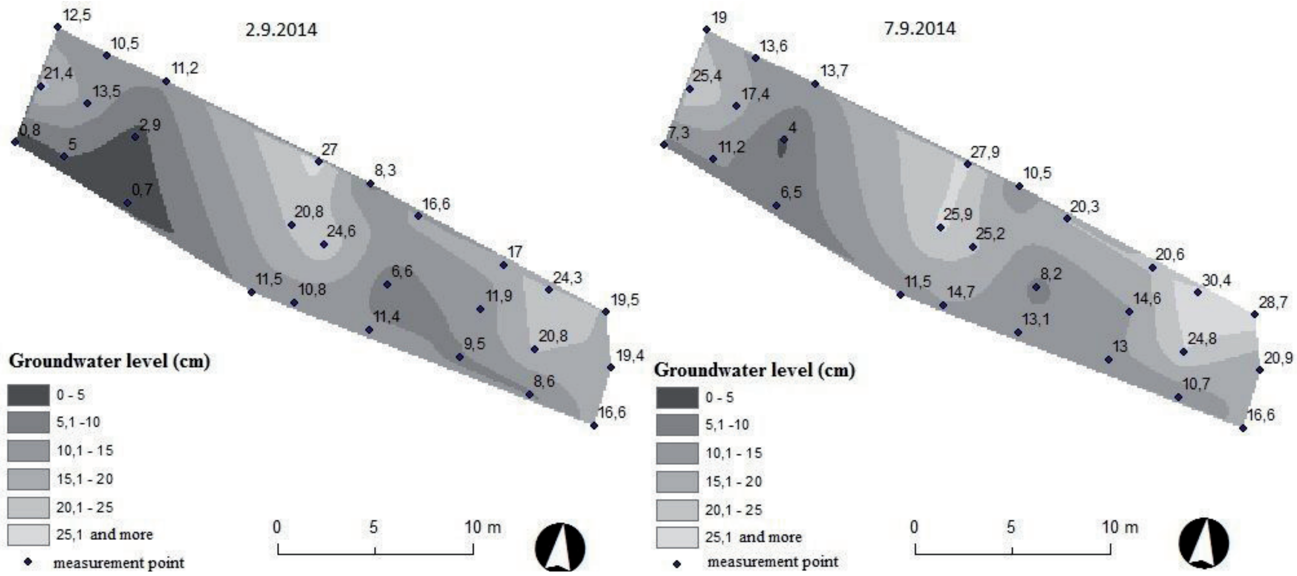


**Fig. 7** Changes of groundwater level during a selected episode of drought between the September 2, 2014 and September 7, 2014. Given numbers in the graph represent measured groundwater levels in centimeters on a given day.

(55.4 mm), was analyzed between the September 11, 2014 and September 15, 2014 at the Rokytka catchment. It is obvious that groundwater level along the drainage ditch shows a high amplitude, see Fig. 6. With longer distance from the drainage ditch, the groundwater level increases and its change during an episode decreases. The level is the highest in the section close to restoration dams. Their influence is perceived as positive, as they raise groundwater level. They also have a stabilizing effect. However, the results also imply that in a certain distance from restoration dams, their effects can no longer be seen and groundwater level fluctuates naturally as in the Peat Bogs, which are not influenced by a drainage. It is also evident that the decreases or increases of water level are very variable and there are noticeable differences between individual points, in spite of the fact that it is a small homogenous area. The difference between the spot with the highest and with the lowest decrease is 6.4 cm. On the contrary, in the areas near restoration dams, the groundwater level was increasing very gradually and a similar increase was reached at all the measurement points.

Another observed episode was during a dry period, when there was only 1.4 mm of precipitation from the September 2, 2014 to September 7, 2014 (see Fig. 7). The smallest changes of groundwater level in a period with low precipitation were reached in the middle line of the observed area, precisely in the distance of 3 m from the drainage ditch. It is interesting that in this episode, rather big amplitudes can be found, even in the area of restoration. It can be caused by the fact that before the period of drought, the groundwater level was very high, precisely right under the surface; hence, following decreases could have progressed faster there. The biggest difference between water levels is significant again and it is even up to 9.2 cm during the monitored five day range. It has been confirmed repeatedly that in the areas located further from restoration, the groundwater level is distinctly lower and, moreover, there is a remarkable and fast fluctuation of groundwater, which is not beneficial for the evolution of mountain Peat Bogs.

## 5. Discussion

The results of the research conducted in Rokytka Peat Bog are in correspondence with other national and international researches concerned with the same subject (Bufková 2013; Vlček et al. 2012; Worrall et al. 2007; Wilson et al. 2011). The most significant finding is that restoration measures have the ability to increase groundwater level and to decrease its amplitude. In this case, it was statistically observed especially in line 1A, which contains data from restoration measures. At the point of restoration, the mean groundwater level was up to 10 cm higher than at a place with no restoration, similar to Worrall et al. (2007). Holden's research (2011) brings the difference of 4 cm. Ketcheson and Price (2011) demonstrated that the size of groundwater level change depends on many factors. Similar results in the Šumava Mts., particularly in the Schachtenfilz Peat Bog, were achieved, for example, by Bufková (2013), who declared that after three years from a restoration, the average groundwater level increased and its fluctuation was considerably reduced, especially in the most disturbed parts of the Peat Bog and in the forest cover of peat and pine grove. In our case it was also statistically significant.

The groundwater level increases more steeply perpendicularly from the drainage ditch in the area of restoration in contrast with the area without restoration. Thus, it can be presumed that restoration measures have an important role in the attenuation of negative effects of a drainage ditch. It was confirmed by a research of Haapalehto et al. (2011) who found that damming and filling of the ditches resulted in a raised groundwater level in the restored bog and fen systems by several centimeters. However, in a certain distance, these differences decrease and groundwater level behaves naturally as in a Peat Bog with no human disturbance. This statement is also confirmed by the work of Wilson et al. (2011). Although, it was revealed that particular changes of groundwater level can be rather variable, in spite of the fact that the researched area was small and very homogenous. Vlček et al. (2012) notes that daily relations of groundwater level are quite fast and they can reach several centimeters during a day. In this case, even higher values were observed in some areas, due to the fact that in the proximity of the drainage ditch, significantly higher amplitudes appeared, compared to the further located areas from it. Thus, it was proven that the influence of restoration measures on groundwater level is positive in this case.

This research has also demonstrated that the evaluation of factors of precipitation and evapotranspiration is sufficient to clarify precisely the changes of groundwater level in Peat Bogs. It is manifested predominantly by high values of correlation and determination coefficients. On the other hand, a little decrease was observed in the groundwater level, even though there was a higher precipitation than evapotranspiration. It could be caused by interception during a low intensity rain. Kellner (2003) and Allott et al. (2009) note that the size of evapotranspiration from wetlands is variable. General factors influencing the evapotranspiration are surface conditions, such as roughness, temperature, and dryness, together with the air temperature, humidity, and solar radiation. Since the climatic factors vary significantly, it is hard to generate absolute values without a great uncertainty.

The correlation of groundwater level with the index of previous precipitation manifested itself in the same manner. An important aspect of the paper was also to refer to space variability of groundwater level changes. Though the observed area is small and homogenous, a high variability in groundwater level changes appeared even during selected episodes. The difference between maximum increase and decrease reached up to 9.2 cm during five days. Ketcheson and Price (2011) reminded that topographical variability and the location of the dams can strongly influence the magnitude of the groundwater level rise at any given location. Price et al. (2003) notes that groundwater level also depends on the depth of the ditch, the distance between ditches, and the hydraulic conductivity of the peat. For example, Wilson et al. (2011) observed conflicting results in a few experimental locations, when after drain blocking, groundwater level was deeper than before blocking. It shows that in a Peat Bog, there are some places with non-standard local specific water regime.

Changes of groundwater level were especially prominent in the areas far from restoration. It was also discovered that the lowest deviations (0.48 cm) were achieved at the automatic station, which is not influenced by melioration. The moving average of the difference between precipitation and evapotranspiration at this point demonstrated that it copies the natural course of groundwater level changes very accurately. This statement is confirmed by another research (Vlček et al. 2012), which was also implemented in Rokytka Peat Bog; similar daily changes were observed, approximately 2–3 cm according to the temperature and precipitation. A rapid and sudden increase of groundwater level during intensive precipitation was also confirmed (Kučerová et al. 2009). Despite the fact that many factors are involved in groundwater level changes, the dependence can be largely explained by the difference between precipitation and evapotranspiration. It was observed also in Wilson et al. (2011).

## 6. Conclusion

The headwater area of the Otava River is characterized by a high portion of Peat Bogs, thus it is an area with a very specific hydrological regime. In the context of the occurrence of hydrological extremes, it is very important to pay attention to the retention potential of the areas.

The most significant outcome of the paper is the demonstration of positive effects of a restoration on groundwater level. It was proven that restoration decreases fluctuation and increases groundwater level, which is essential for a natural evolution of a mountain Peat Bog. The main factors of groundwater level fluctuation are predominantly evapotranspiration and precipitation; the explanation of this phenomenon is demonstrated by high values of determination and correlation coefficients. The paper thus contributes to the understanding of the retention potential of peat complexes, which is essential for the understanding of the hydrological regime of the Otava River. This part of the Šumava Mts. can consequently offer other valuable findings, due to its significant retention potential.

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# DEMOGRAPHIC DIMENSION OF SUBURBANIZATION IN UKRAINE IN THE LIGHT OF URBAN DEVELOPMENT THEORIES

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**ABSTRACT**

Suburbanization is the most typical process that defines the development of urbanized areas in Central and Eastern Europe. However, in Ukraine, except for the largest cities, suburbanization process seems to be underestimated. This paper is trying to estimate the actual extent of suburbanization in Ukraine, find out the relationship between the city size and the development of suburbanization, reveal regional peculiarities, and finally, evaluate successfulness of the common urban evolution theories in explanation of empirical evidence from one of the largest Eastern European countries. Analysis is based on the data on migration dynamics in urban cores, peri-urban areas and hinterlands of 65 cities with a population of over 40,000 located in 22 regions of Ukraine. It was found out that suburbanization processes in Ukraine are extremely widespread and define general course of current urban evolution. Migration growth of peri-urban area, comparing with main city and hinterland, is observed in more than half of studied cities (53%), including all cities with population over 100,000. Urban dynamics in Ukraine seems to be rather evolutionary than involutionary and therefore similar to other Eastern European countries. However, large-scale restructuring of the economy in post-Soviet period had a critical role for the development of individual and regional differences in urban development and caused several biases from "normal" urban evolution: some patterns and stages are rather debatable and may essentially differ from their classical Western prototypes. Verification of these conclusions can be done through further in-depth research of certain cases.

**Keywords:** suburbanization, urban evolution, theories of urban development, migration dynamics, Ukraine

Received 3 February 2017; Accepted 1 June 2017; Published online 24 August 2017

## 1. Introduction

Contemporary human geography deservedly focuses on urban areas. Today, cities worldwide demonstrate extraordinary dynamism and play a defining role in shaping geospatial functional framework from local to global levels. Thus, question of the completeness and reliability of scientific knowledge on urban development is of particular importance.

Suburbanisation is the most typical process that defines the development of urbanized areas in Central and Eastern Europe. Evidences for this assertion may be found in wide scientific literature. Suburbanization processes have been identified and described in many post-socialist countries, including Post-Soviet; among them the Czech Republic (Sýkora 1994; Sýkora and Čermák 1998) Sýkora and Novák 2007; Ouředníček 2007), Slovakia (Matlovič and Sedláková 2007; Slavík et al. 2011); Slovenia (Ravbar 1997), Hungary (Brown and Shafft 1994; Kovács 1994; Kok and Kovács 1999; Timár and Váradi 2001), Estonia (Ruopilla 1998; Tammaru et al. 2004; Tammaru 2005; Kontuly and Tammaru 2006; Tammaru and Leetmaa 2007; Leetmaa et al. 2009), Latvia (Krisjane and Berzins 2012), Poland (Kupiszewski et al. 1998; Szymanska and Matzak 2002), Bulgaria (Valkanov 2006; Hirt 2007), Russia (Blinnikov et al. 2006; Makharova 2007), as well as in international perspective (Sailer-Fliege 1999; Brade et al. 2009; Phelps and Wu 2011; Stanilov and Sykora 2014). However, suburbanization in Ukraine remains, to a large extent, outside the field of view of researchers. The majority of urban studies focus on the cities within their administrative limits, while the development of peri-urban areas, constituting an integral functional unit with the city, remains beyond vision. However, such an approach will probably lead to erroneous output: e.g., Dotsenko (2010) in certain cases comes to deceiving conclusions of urban dynamics in Ukraine on these grounds.

As a rule, suburban areas of Ukrainian cities get attention of researchers only in end-to-end studies of urban systems and only in cases of the largest cities with relatively big satellites: the latter have too specific demographic dynamics, and this fact cannot go unnoticed. Suburbanization and metropolization around the largest Ukrainian cities have become subjects of close attention (Mezentsev and Mezentseva 2012; Mezentsev 2013; Nemets and Mazurova 2014; Manshylina 2015). Simultaneously, suburbia of smaller cities is constituted by small settlements officially not classified as urban, and therefore is largely ignored. When reading scientific literature (with few exceptions) one may have an impression that suburbanisation processes do not exist at all around these cities. The only one detailed comprehensive study revealing the processes around medium-sized Ukrainian city deals with the suburban area of Ivano-Frankivsk (Zakutynska and

https://doi.org/10.14712/23361980.2017.12
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AUC Geographica, 52, No. 2, pp. 151–163

Slyvka 2016). In-depth study on socio-spatial inequality and polarization of regional development in Ukraine (Mezentsev and al. 2014) contains no term "suburbanization" at all. Pylypenko (2010) emphasizes on intensive spatial redistribution of the rural population, in particular, its increased concentration in administrative districts around regional capitals during 1991–2011. However, this author considers these facts only as evidence of strengthening polarization of the rural population as a result of different speed of demographic decline, and does not associate them with suburbanization. The paper of Baranovsky (2011) also encloses conclusions on increasing disparities between rural settlements in peri-urban areas and hinterlands, but again, these processes are considered without any regard to suburbanization and urban evolution.

Comprehensive understanding of suburbanization in Ukraine is impossible without closer view on the more general scientific problem of urban evolution and its peculiarities in post-Soviet conditions. Therefore, taking into account listed above, this paper tries to answer the following questions. First, what is the actual extent of suburbanization in Ukraine, i.e. what cities are at suburbanization stage: only the largest or less populous too? Second, which is the relationship between the city size and the development of suburbanization? Third, in what way regional differences in economic and social development influence the trajectories of urban development? Finally, do suburbanization processes in Ukraine fit generally accepted urban evolution theories?

## 2. Theoretical background

The Western geographical literature since 1960s, starting from Gibbs (1963), Berry (1976), and Kasarda (1977), contains wide discussion on urban evolution. This discussion was marked by continuous search for consensual conceptualization of suburbanization. For many scholars, espousing the simplest and the most universal idea, suburbanisation is defined as an absolute or relative growth of peri-urban areas (Hall and Hay 1980; van den Berg et al. 1982; Cheshire and Hay 1989; Cheshire 1995; Valkanov 2006). Tammaru (2001) distinguishes between suburban growth (positive change of population in peri-urban areas) and actually suburbanisation (relatively quicker growth of suburban areas as compared to the central city).

While Gibbs (1963), Klaasen et al. (1981), van den Berg et al. (1982), Champion (2001) and others considered suburbanization as one of the consequent stage of urbanization process, some other scholars proposed to focus not at the development stages but rather processes dominating in certain urban system. E.g., Berry and Kasarda (1977) distinguished the processes of deconcentration (decrease in central city density), decentralisation (faster growth rate in the outer urban units) and suburbanisation (movement of people from city to suburban area). Lindgren (2003) differentiated between suburbanisation, counter-urbanisation, population retention (within suburban areas), and centripetal migration (to suburban areas). Ouředníček (2007) suggests that not only urban core but the whole urban region including peri-urban area and rural hinterland is characterized by dominated process: urbanisation, suburbanisation, deurbanisation, or reurbanisation. Kliuiko (2013) proposes to differentiate between urbanization, suburbanization, re-urbanization, exurbanization (commuter settlements beyond suburbia), counter-urbanization and post-suburbanization.

Recently, great attention is paid to the process of post-suburbanization leading to combination of urban and rural lifestyle (Borsdorf 2004). Unlike suburbia, post-suburbanization settlements are less dependent from the main city because their inhabitants may find work without leaving own settlement (using, e.g., remote working). Another common recognized post-suburbanization feature is gentrification, especially in largest cities, implicating renovation and colonization of central urban areas by the new rich (Badyina and Golubchikov 2005; Golubchikov et al. 2009).

In this study we decided to focus on the most universal theories of staged urbanization, emphasising on the general urban development trend. First one was proposed by Gibbs (1963), who argued for the 4 basic stages of urban development. The first stage is characterized by rapid urban growth, caused by intensive migration of the rural population into cities due to the greater attractiveness of urban lifestyle. Then the stage of "urban saturation" comes, marked by a start of migrations to suburban area; however, the main cities continue to grow faster than the suburbs. The third stage of "suburbanization" is marked by faster demographic growth of suburban areas as compared to the main city. Finally, the stage of urban de-concentration is characterized by migration outflow from both main city and suburbia to the rural hinterland. However, at this stage the rural way of life becomes completely similar to the urban one, so that urban and rural settlements differ, besides the size, only in the architectural and planning characteristics.

The second theory (Klaasen et al. 1981; van den Berg et al. 1982; Champion 2001) proposes to outline four stages of urban development according to the prevailing directions of migration and the processes occurring in the main city, suburbia, and hinterland. The first stage is marked by urbanization, conceptualized as the process of rapid growth of the main city population and extreme concentration of people, jobs, production, services in the cities with the simultaneous migration outflow from the surrounding rural communities. The second stage may be recognized by the outflow of population, searching for better living conditions and lower living cost, from the main city to suburbia, which begins to outpace the rate of main city growth. However, inhabitants of suburban area maintain close relationship with the main city since they continue to work and receive most services there. Simultaneously, population of the main city continues to grow primarily through migration outflow from the hinterland. The third stage represents the process of centrifugal movement from the main city and sometimes suburbia to the small cities and rural settlements, resulting in absolute or relative demographic growth of hinterland. This stage, called des-urbanization or counter-urbanization, later was discussed by Vartianen (1989), Sjöberg (1992) and others. Finally, the fourth stage of the so-called re-urbanization represents renewed demographic growth of the main city explained by gentrification and revitalization of industrial areas; main city population starts growing once again or at least decline more slowly than population of suburbia.

The third one is a theory of differential urbanization, first proposed by Geyer and Kontuly (1993) and over the last two decades constituting a framework for debates on suburbanization. The corresponding models determine the stages of urban dynamics by the ratio of migration balance or overall population dynamics in the three categories of settlements: major cities, medium-size cities and small cities together with all other settlements. According to theoretical constructs, supported by empirical research from the various countries, urban development cycles are similar but differentiated in time in cities of different size. This suggests that not only the biggest, but also medium-size and small cities may reach the stage of suburbanization, but with some chronological delay. However, Ouředníček (2007) emphasises that such an approach is excessively quantitative and does not pay due attention to the composition of migration streams, people's motivations and regional peculiarities.

However, these theories may have some limitations in post-Socialist, especially post-Soviet, conditions. First, in Soviet times classical suburbanization did not occur due to the total absence of basic prerequisites, like wide scale social stratification, private land use, profit-seeking real estate sector, availability of individual means of transportation etc. Therefore, there is a possibility that after the end of Socialist system some cities (possibly largest and/or most economically vibrant) jumped very quickly to the stage of suburbanization (or even desurbanization and reurbanization, passing them in accelerated mode). On the other hand, economically depressive cities may have skipped the suburbanization phase and directly started to lose population; however, some of such cities may renew economic growth and return to urbanization or suburbanization stage. Taking into account extremely high spatial polarization in Ukraine, this possibility looks like very probable. Demographic statistics tells that the absolute majority of Ukrainian cities experienced demographic decline in 1990s, and even in 2016 more than 80% of them still lose population. Therefore, in many cases we may expect unusual sequence of urban development stages. Differential urbanization model was tested on empirical material from Ukraine by Mezentsev and Havryliuk (2015). These authors confirmed the applicability of differential urbanization model to explain the development of urban regions in Ukraine. However, they conclude that classical urbanization stages hardly can be distinguished in the Post-Soviet period. These authors found out that after 2005 migration attractiveness of major Ukrainian cities went down, while small cities increased their attractiveness; however, after 2010 major cities once again restored their migration growth.

The other important question is the nature of peri-urban demographic change in case of post-socialist cities. The most defining characteristic of true suburbanization is an outflow of rich people from the urban core to periphery searching a higher-quality lifestyle (Jackson 1985; Fishman 1987; Vartianen 1989). However, rural migrants may also settle in peri-urban area in order to find economic opportunity and simultaneously to avoid high living expenses associated with life in urban core; this process also leads to the accelerate peri-urban grows, but differs from true suburbanization. Following this line of reasoning, Hirt (2007), based on in-depth literature analysis, makes conclusion about three possible forms of peri-urban growth: classical western suburbanization (when affluent households leave the city in search of a higher quality of life), urban ruralisation (survival strategy of poor households relocating from cities to peri-urban areas in order to work rural plots of land and produce their own food (e.g. Seeth et al. 1998; Smith 2000)), and rural urbanization (when fringe of the most economically vibrant cities may attract relatively poor migrants from the immediate hinterland as well as migrants from lower-order provincial towns, which is typical of developing countries). Krisjane and Berzins (2012) pointed out that suburbanisation in Post-Soviet space is a socially polarised process: people with both high and low social statuses are more likely to move to the suburbs than those from middle class. Nevertheless, people, living in Soviet prefabricated apartment buildings, widely use new opportunities to improve their living conditions by moving to suburban areas (Borén and Gentile 2007). The study of Sofia's suburbia, which included field survey of newcomers (Hirt 2007) proved the existence of Western-style suburbanization, but did not reject the possibility of rural urbanization and urban ruralisation. However, we should have in mind difference between the level of economic development and incomes between Bulgaria (even in 2007) and Ukraine, as well as the fact that the example of Sofia is not a good one for the majority of Ukrainian cities, except for the largest.

## 3. Ukraine as a case

The urban population is only one among factors influencing the potential for suburbanization: urban socio-economic development should play even more decisive role. Ukrainian territory is characterized with considerable natural, economic, and socio-cultural diversity constituting the basis for regional differences in urban development trajectories. The complexity of urban studies in Ukraine is explained by extremely high topological, functional, and morphological diversity of 460 Ukrainian cities.

The current level of urbanization in Ukraine (69.5%) significantly exceeds the global average, but is inferior to the European average (73.4%). Over the last 20 years, the proportion of urban population in Ukraine grew by 3%. In the Western part of the country, rural population still dominates and constitutes a significant demographic reserve for the future urban growth. However, in Eastern Ukraine the level of urbanization reaches 80–90%, therefore rural demographic reserves for urban growth are almost depleted. Rural population density largely depends on natural conditions: extreme values (more than 100 people per km$^2$) are typical for Subcarpathia and Transcarpathia, relatively high values (50–70 people per km$^2$) are observed in the forest-steppe belt and Crimea, and low values (30–40 people per km$^2$) are typical for Southern and Eastern Ukraine, as well as for the northern forest region of Polessia along the Belarusian border.

Hypothetically, the overall gradient of suburbanization intensity depends on the differences in the historical development. In Central and especially Western Ukraine, the majority of cities has a long lasting development tradition and grew based on continuous economic and social relationships with the surrounding countryside. Residential development in these cities largely consists of low-rise private buildings; moreover, local inhabitants has a strong tradition to live in own private estates and to have their own subsidiary husbandry in addition to the basic employment. From this perspective, urban residents in these regions have high psychological readiness to change their apartment blocks for private estates in the suburbs. In contrast, the majority of cities in Eastern and Southern Ukraine have relatively short history and from the very beginning developed as industrial centres relatively independent from the surrounding countryside. Thus, it can be assumed that historical and cultural background contributes to the larger spread of suburbanization in Western and Central Ukraine and hampers its development in the Southern and Eastern Ukraine, especially in industrial regions. Significant amounts of remittances from labour migrants working in the EU is an additional factor in favour of more rapid growth of suburban areas in Western Ukraine: the lion's share of these revenues are invested in private housing, which is possible mostly in suburbia.

However, adverse environmental conditions, typical for most industrial cities, especially those based on mining, chemistry, and metallurgy, progressively push the population to the suburbs in search for more favourable living conditions. This factor may mitigate to some extent the disparity between the intensity of suburbanization around cities in industrial and agrarian environment.

Deep polarization of socio-economic development, including a sharp spatial differentiation in income rates between main urban cores and the rest of the territory, is another factor that should influence the spatial pattern of urban development in Ukraine. Although the agricultural sector now accounts for a substantial share of Ukraine's GDP, the real countryside is predominantly depressed. These circumstances stimulate intense migration from rural areas. The largest cities with high incomes and diversified structure of the economy are expected to be the main recipients of migrants. These cities include the capital (Kyiv) and also the main macro-regional centres: Kharkiv (North-East), Odessa (Black Sea Region), Lviv (Western Ukraine), Dnipro (Prydniproviya), and, before 2014, Donetsk (Donbas). Since the middle of XX century these urban cores have been already surrounded by constellations of satellite cities, and today constitute the nuclei of rapidly developing metropolitan regions with extremely high concentrations of population and economic activity. Almost all other regional capitals are smaller, but also important centres of economic activity. Some of them are undergoing rapid economic development as a result of successful local management and/or a good geospatial position relative to major cities, e.g., Vinnytsia, Lutsk and Chernivtsi, playing the role of informal regional capitals for Podolia, Volhynia, and Bukovina, respectively.

However, it is worth noting that demographic dynamics of the regional capitals is influenced not only by their own economic viability, but also by socio-economic development of the adjacent region. Low incomes, as well as large share and density of the rural population, should correspond to the more intense migration flows to the regional capitals, including the large proportion of migrants settling in the peri-urban area because of the lower living cost compared to the inner city.

The most of small towns in Ukraine undergo degradation of economic basis, erosion of the functional profile and demographic decline. These trends, in certain way, are apparent in all Ukrainian regions, while their intensity depends on the urban functional profile, its resilience, and flexibility. Simultaneously, Ukraine represents a number of successful urban adaptations to the new socio-economic conditions, including revitalization of previously existing branches and/or the emergence of new ones. Therefore, the spatial distribution of economically successful small towns does not have any clear regional pattern. However, other things being equal, more intense economic development have towns in Western Ukraine due to stronger traditions of entrepreneurship and, once again, financial support from EU migrants.

Since 2014, internally-displaced persons from annexed Crimea and conflict-stricken Donbas are an important component of the overall picture of migration in Ukraine. According to official sources, the total number of internally-displaced persons varies from 1.0 to 1.7 million, the majority of them (98%) come from Donbas, and only 2% from Crimea. Besides the capital, most of internally displaced persons were registered in the Eastern regions adjacent to the military conflict. This suggests that a significant proportion of migrants intend to return to previous residential places; at the same time, a significant number of such persons register outside the occupied territory only to receive social benefits, actually living at home. Unfortunately, a detailed statistics on the distribution of internally-displaced persons between settlements is unavailable.

## 4. Data and methods

This study is focused exclusively on the demographic dimension of suburbanization and encompasses 65 cities with a population of over 40,000 located in 22 administrative regions of Ukraine. Cities in annexed Crimea, as well as in Donetsk and Luhansk regions, affected by on-going military conflict, were excluded from the analysis. Urban cores, peri-urban areas and hinterlands, constituting together integral urban regions, were defined to be spatial units for analysis. Urban core was considered as a main city within its administrative limits. In most cases, peri-urban area was considered within an administrative raion surrounding the respective city. If the main city has no own administrative raion, peri-urban area was determined within several administrative raions surrounding the main city from all sides. Satellite cities constituting separate administrative units (cities of regional subordination) were also included into peri-urban area. Furthermore, peri-urban areas of the major cities, where suburbanization processes have gone clearly beyond the limits of peri-urban administrative raions, were additionally expanded (adding Borodyanka, Vasylkiv and Makariv raions for Kyiv; Chuhuyiv and Zmiyiv raions, as well as the city Chuhuyiv, for Kharkiv; Verhniodniprovskyi raion with the city of Vilnohirsk and Novomoskovsk raion together with the city of Novomoskovsk, for Dnipro). In all cases, hinterland was considered in the limits of administrative raions adjacent to the external limits of the respective peri-urban area except for cities of regional subordination and administrative raions already included in the peri-urban areas of the other tested cities.

This approach make possible to reveal deviations of migration processes in peri-urban area compared to hinterland. Assumption is that significant differences in migration balance between peri-urban area and hinterland are caused by the influence of the main city. The coefficients of the migration dynamics for urban cores, peri-urban areas and hinterlands were calculated according to the formula:

$$K = \frac{\sum_{2007}^{2016} BM}{10 \times \sum_{2007}^{2016} Pop} \times 100\%$$

BM here is a balance of migrations in the corresponding year; Pop stays for a population in the corresponding year. The coefficients of migration dynamics in urban core, peri-urban area and hinterland were marked by the letters C, P, and H, respectively.

However, the actual size of suburbia may significantly differ. In particular, suburbia of small cities may be much smaller comparing with peri-urban administrative raion. This may lead to a systematic underestimation of suburbanisation processes around small cities and overestimation around major cities. Based on the assumption that the population of the peri-urban area should be roughly proportional to the population of the main city, we decided to use, in cases, when P > 0, adjusted coefficient $P_{adj}$, calculated as follows:

$$P_{adj} = \frac{P \times P_o \times Pop_p}{Pop_c}$$

P here is coefficient of migration dynamics in peri-urban area for given city; $P_0$ is coefficient of migration dynamics in benchmark (etalon) city; $Pop_c$ and $Pop_p$ stay for 10 year average of population of the main city and the peri-urban area respectively. The city of Vinnytsia was chosen to be the benchmark city since the outer limits of its suburbia roughly coincide with the limits of respective administrative raion. Having intent not to overload the text, hereinafter P is written instead of $P_{adj}$.

In addition, an attempt was made to estimate the intensity of suburbanization using the following formula:

$$I = I_1 + I_2$$

$$I_1 = P - H$$

$$I_2 = \begin{cases} P - C, \textit{ if } P - C \geq 0 \\ 0, \textit{ if } P - C < 0 \end{cases}$$

The intensity of suburbanization I is a sum of two components. The first component $I_1$ shows the excess of migration dynamics in the peri-urban area over the respective value for the hinterland. Therefore, it reflects the impact of the city on its peri-urban area. The second component $I_2$ shows the excess of migration dynamics in the peri-urban area over the respective value for the main city. This component is meaningful only when such excess is actually observed.

Three methodological limitations of this study, proceeding from the above, should be preconditioned. First, although the coefficient P was adjusted, we still do not know the actual size of suburbia in different cities. Second, erroneous conclusions are possible in the case when the differences in migration balance between the suburban area and hinterland are caused by other factors than the main city influence. Third, obtained results say little about the specific vectors of migration flows and their participants, which makes impossible an unambiguous conclusion about the nature of the dominant process: is it classical suburbanization, or urban ruralisation, or rural urbanization? Unfortunately, Ukrainian official statistics do not contain detailed information on specific migration flows (i.e. we know destinations of migrants but do not know from where exactly they come). Therefore, the real ratio of migration flows generated by classical suburbanization, urban ruralisation and rural urbanization remains unclear and requires further studies.

## 5. Results and discussion

Actually, there is no correlation between the main city population and migration dynamics in urban core (Figures 1a, 1b). Coefficient of migration dynamics in peri-urban area also has wide range of values even for cities with similar population. Nevertheless, general trend involves a clear linear dependence: cities with large populations have better migration dynamics in peri-urban areas. However, cities with population over 500.000 have abnormally low values of the coefficient P (Figures 1c, 1d). The same refers to the coefficient of suburbanization intensity (Figures 1e, 1f). These findings indicate that the rate of peri-urban growth depends on the city size, except for the largest cities.

The dependence between the components $I_1$ and $I_2$ is linear, moreover, $I_1 \approx I_2$ (Figure 1g). This suggests that the growth of migration attractiveness of suburbia in comparison with hinterland is roughly proportional to the growth of migration attractiveness of suburbia in comparison with the main city, which corresponds to the hypothesis of classical suburbanization.

The values and the ratios of the calculated coefficients of migration dynamics for urban core, peri-urban area and hinterland (Figure 2), as well as the coefficient of suburbanization intensity, made it possible to identify several groups of the studied cities / urban regions.

The first group (1) includes cities with rapid migration growth in the urban core ($C > 0$) on the background of negative demographic dynamics in the peri-urban area and hinterland ($P < 0$; $H < 0$), which indicates that the process of urbanization in its purest form. This group consists of small and medium-sized cities with a stable economic development, located in the regions with relatively high density of rural population. These cities are powerful attractors of migrants from their peri-urban areas and hinterlands.

Cities from the second group (2) have migration growth in both main city and peri-urban area amid hinterland ($C > 0$; $P > 0$; $C > H < P$). This group includes three subgroups:

The first subgroup (2.1) includes cities with rapid or moderate migration growth of the main city (0.15–0.90%), slow migration growth in peri-urban area (0.08–0.14%) and migration outflow from hinterland. Thus, the process of migration growth in urban core still dominates, but the growth of peri-urban areas is also visible. This subgroup consists of three regional capitals. Two of them, Chernivtsi and Ivano-Frankivsk, are located in Subcarpathia, region with an extremely high density of rural population and the lowest share of urban population. These cities are quite dynamic poles of economic development with the dominance of the service sector and high quality of life. All of these factors contribute to the rapid migration growth of these cities. The third regional capital, Mykolayiv, is located in the Black Sea region. This case is much more problematic to explain as the city nowadays has no sufficient number of working places even for the already living residents due to the shrinking industry, and is located in the region with quite low density of rural population. The only possibility that could be proposed is that this city is used by the migrants from hinterland as a springboard for further movement to other, larger and more prosperous cities.

The second subgroup (2.2) includes cities with rapid migration growth of peri-urban area (usually 0.7–1.2%) and relatively low migration growth of the main city (0.01–0.19%), while hinterland is losing population. This subgroup consists of regional capitals (Khmelnytskyi, Lutsk, Vinnytsia, Poltava, Chernihiv) and regional sub-centres (Kremenchuk, Bila Tserkva, Melitopol, Berdiansk, and Okhtyrka). Most of them are characterized by a dynamic and diversified economy, in particular rapid development of the service sector. Some of these cities such as Vinnytsia, Lutsk and Khmelnitsky traditionally are in the top of the Ukrainian city rankings for quality of life, therefore it is considered fashionable and prestigious to live in these cities. Therefore, these cities and their peri-urban areas are attractive destinations for migrants from hinterland. At the same time, wealthy and and middle class people are seeking to move to suburbia. As a result, peri-urban area is experiencing a very intense migration growth, while the growth rate of the main city is slowing down, although remains positive.

The third subgroup (2.3) includes urban regions with positive migration dynamics in the all of structural elements ($C > 0$; $P > 0$; $H > 0$). Therefore, we may suggest in-migration of population from outside the urban region and large radius of the main city influence on the surrounding area. The rates of migration growth in the main cities are among the highest in the country (0.26–0.47%), however, the migration growth in peri-urban areas is even higher ($C < P$) and almost the same as in the previous group of cities (0.50-1.03%). At the same time, P values are abnormally low if they are considered from the perspective of the early identified dependence of the migration dynamics in peri-urban area on the main city population. This subgroup includes Kyiv, Kharkiv,

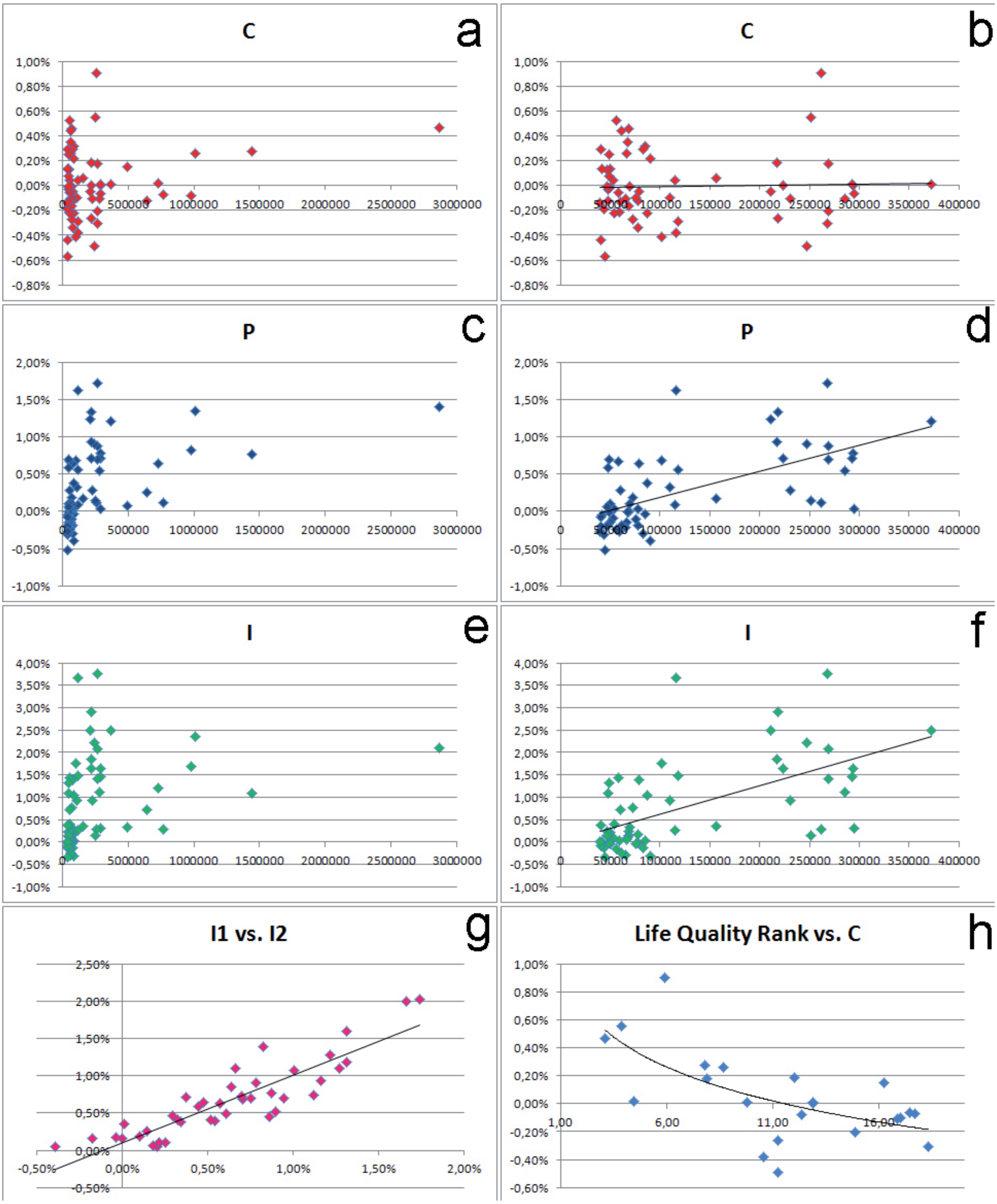


**Fig. 1** Dependence of migration dynamics and intensity of suburbanization on the city population and quality of life.

Odessa, and Lviv, inter-regional functional cores with a diversified structure of the economy, rapid development of the service sector, the highest average per capita income among major cities, high quality of life, and great opportunities for professional fulfilment. Thus, these cities have the most favourable conditions for the development of the middle class constituting the demographic basis for the classical suburbanization. Simultaneously, these cities are extremely attractive to migrants from all over the country. These factors lead to intensive growth of both main cities and peri-urban areas. It should be noted that the high demand for real estate in the suburbs leads to higher prices which sometimes may be compared with the prices in the main city; simultaneously, the main city

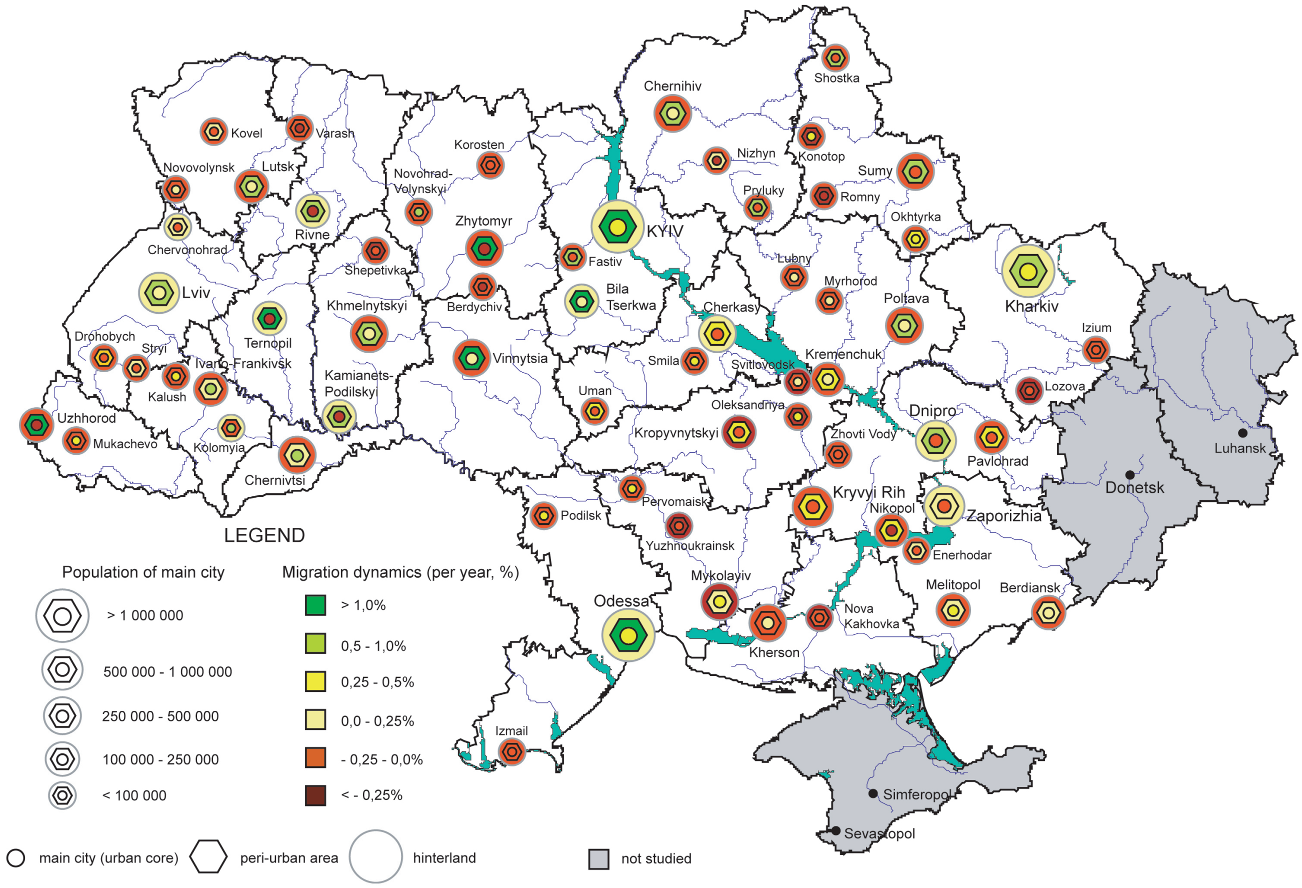


**Fig. 2** Migration dynamics in urban cores, peri-urban areas, and hinterlands.

has difficult transport accessibility for residents living in peripheral parts of suburbia. Therefore, the main city may be even more attractive and accessible for migrants than suburban area. This indicates the possibility of reurbanization process, including new residential development inside the main city by revitalizing former industrial and warehouse areas.

Cities from the second group (3) have positive migration dynamics only in peri-urban area, while the main city loses population (C < 0; P > 0). These cities usually have moderate to high migration growth of peri-urban area and moderate rate of migration outflow from the main city at nearly zero migration balance in hinterland (H ≈ 0). This group is sufficiently numerous and consists of 20 cities, including 10 regional capitals (Uzhhorod, Ternopil, Rivne, Zhytomyr, Cherkasy, Kropyvnytskyi, Kherson, Sumy, Dnipro, Zaporizhia) and 9 sub-regional centres (Stryi, Kovel, Kamianets-Podilskyi, Uman, Nizhyn, Pryluky, Shostka, Kryvyi Rih, Pavlograd, and Nikopol). Since the sub-group brings together cities with different population, specific values of C and P coefficients may differ substantially. E.g., coefficient P varies from 0.52% to 1.37% for big cities and from 0.03% to 0.49% for medium-sized and small cities; coefficient C varies from −0.49% to −0.07% for big cities from −0.41% to −0.01% for medium-sized and small cities. These figures point to the lack of migration flows from hinterland to the main city. However, the urban core is losing population, and peri-urban area should be a recipient for at least part of these migrants. In general, these cities are similar to the cities of subgroup 2.2, but are characterized by lower level of economic development and/or less diversified economy. Therefore, these cities have relatively low attractiveness for migrants from hinterland. However, these cities, due to spatial concentration of people, constitute powerful markets for goods and services, and have much better infrastructure than the surrounding region. It stimulates the people from respective hinterlands to relocate to peri-urban areas. On the other hand, although middle class here should be much less powerful than in the cities from previous subgroups, motivation of such people to improve living conditions should be even greater, taking into account low quality of life, negative image of the city and, in many cases, environmental problems connected with industry. Also, we may assume the presence of urban ruralisation: impoverished middle-aged and elderly urban population may move to peri-urban area to have subsidiary plots there.

Urban regions from the fourth group (4) experience rapid migration from both the main cities and peri-urban areas compared to hinterland (C < 0; P < 0; C < H > P). The first subgroup (4.1) includes urban regions, where the main city is losing population while migration dynamics in peri-urban area and hinterland is much better and about the same ($C < 0$; $P > C < H$; $P \approx H$) or much worse and around the same ($C < 0$; $P < C > H$; $P \approx H$). This means that the depressed state of the city has almost no effect on the surrounding area due to the lack of sustainable economic ties. This subgroup includes small and medium-size industrial cities dependent on a narrow range of activities: oil refinery, salt making, and heavy engineering in Drohobych; coal mining in Chervonohrad; enrichment of uranium ore in Zhovti Vody; nuclear energy in Energodar, Yuzhnoukrainsk and Varash; railway operation in Fastiv. The second subgroup (4.2) includes urban regions where both the main city and peri-urban area are losing population, but the migration dynamics in hinterland is significantly better ($C < 0$; $P < 0$; $C < H > P$). This subgroup includes medium-sized cities in the agricultural environment (Romny, Berdychiv, Korosten, Shepetivka, Izmail), formerly specialized in the processing of agricultural raw materials originated from the surrounding countryside. The third subgroup (4.3) includes urban regions entirely losing population, but the migration outflow is smallest in the main city and largest in the hinterland ($C < 0$; $C > P > H$). This means that the main city is depressive but it still has a positive effect on its surroundings and keeps them from deeper stagnation. This subgroup consists of Izium, Lozova, and Nova Kakhovka, medium-sized industrial cities, located in agricultural environment far away from the regional capital.

Among all the studied urban regions, 37 (58%) have a positive migration dynamics in peri-urban area significantly exceeding the respective indicator for hinterland. In 34 urban regions (53%), migration inflow in peri-urban area is higher than in the main city; this number includes also those 20 urban regions (31%), where the main city is losing population, but the peri-urban area continues to grow. This once again proves the role of suburbanisation as the most typical characteristic of the spatial distribution of the population in Central and Eastern Europe (Krisjane 2002).

Also, we may conclude that regional economic specificity plays an important role, influencing the country-wide pattern of urban and peri-urban growth. Although peri-urban growth is typical for cities in all parts of Ukraine, peri-urban areas of economically dynamic cities probably receive migrants both from the urban cores and hinterlands, while peri-urban areas of cities in economic stagnation receive migrants mainly from the urban cores. On the other hand, more rapid growth of urban cores is associated, first, with high share of rural population in the hinterland, second, with high incomes and high quality of life and, third, well-shaped urban image. These circumstances lead to a paradoxical (at first glance) situation when the growth of main city rather than the growth of suburbia points on the economic prosperity of the city. In support of this, see also chart (Figure 1h) displaying dependence between average life quality ranking (2007–2017, by Journal "Focus", Rating Sociology Group, and International Republican Institute) and migration dynamics in the main city for 22 Ukrainian regional capitals. At the same time, mono-functional cities, especially those specialized in production of raw materials, energy sector, classical heavy industry or food material processing, have less opportunities to retain the demographic growth, in both urban core and peri-urban area.

Obtained empirical data indicate the dependence of suburbanization processes in Ukraine on the city size. First, as has been shown above, the average migration dynamics in peri-urban area and the intensity of suburbanization is directly proportional to the population of the city, although this pattern is violated for cities with a population of more than 500,000. Second, the migration growth of peri-urban areas is typical only for 8.3% of cities with population up to 50,000, while among cities with population from 50,000 to 100,000 this figure rises to 26%, and among cities with population over 100,000 is constitutes almost 100%. By contrast, rapid migration growth in the urban core on the background of negative demographic dynamics in the peri-urban area is observed in 33% of cities with a population up to 50,000, in 39% of cities with a population from 50,000 to 100,000, and in all cities with a population over 100,000.

The next step of analysis was aimed to access the correspondence of revealed empirical data to the common theories of urban evolution. It is logical to assume that described above groups and subgroups of cities (at least some of them) may correspond to specific stages of urban development.

Obviously, the cities from group 1 are on the stage of urbanization. Cities from subgroup 2 combine the processes of urbanization and suburbanization in different proportions. Cities from subgroup 2.1 demonstrate both urbanization and suburbanization process, but the first still prevails. This corresponds to urban saturation stage, proposed by Gibbs, or to the early phase of suburbanization according to Klaasen and van den Berg. Cities from subgroup 2.2 experience quick migration growth in peri-urban area and slow migration growth in the main city. This pattern corresponds to suburbanization stage according to both theories. Cities from subgroup 2.3 are among the largest in the country and differ from the previous subgroup by higher rate of migration growth in the urban core. Therefore, we may assume that they have advanced far ahead in their evolution and reached the stage of reurbanization. This suggestion is supported by cited above conclusions of Mezentzev and Havryliuk (2015).

Cities from group 3 demonstrate only suburbanization process. However, it is difficult to clearly interpret the cities from group 3 within the framework of urban development theories. On the one hand, it may be the next stage of urban evolution, which follows the stage, represented by subgroup 2.2 (deconcentration or desurbanization). However, as follows from the previous analysis, the cities from subgroup 2.2 and group 3 may

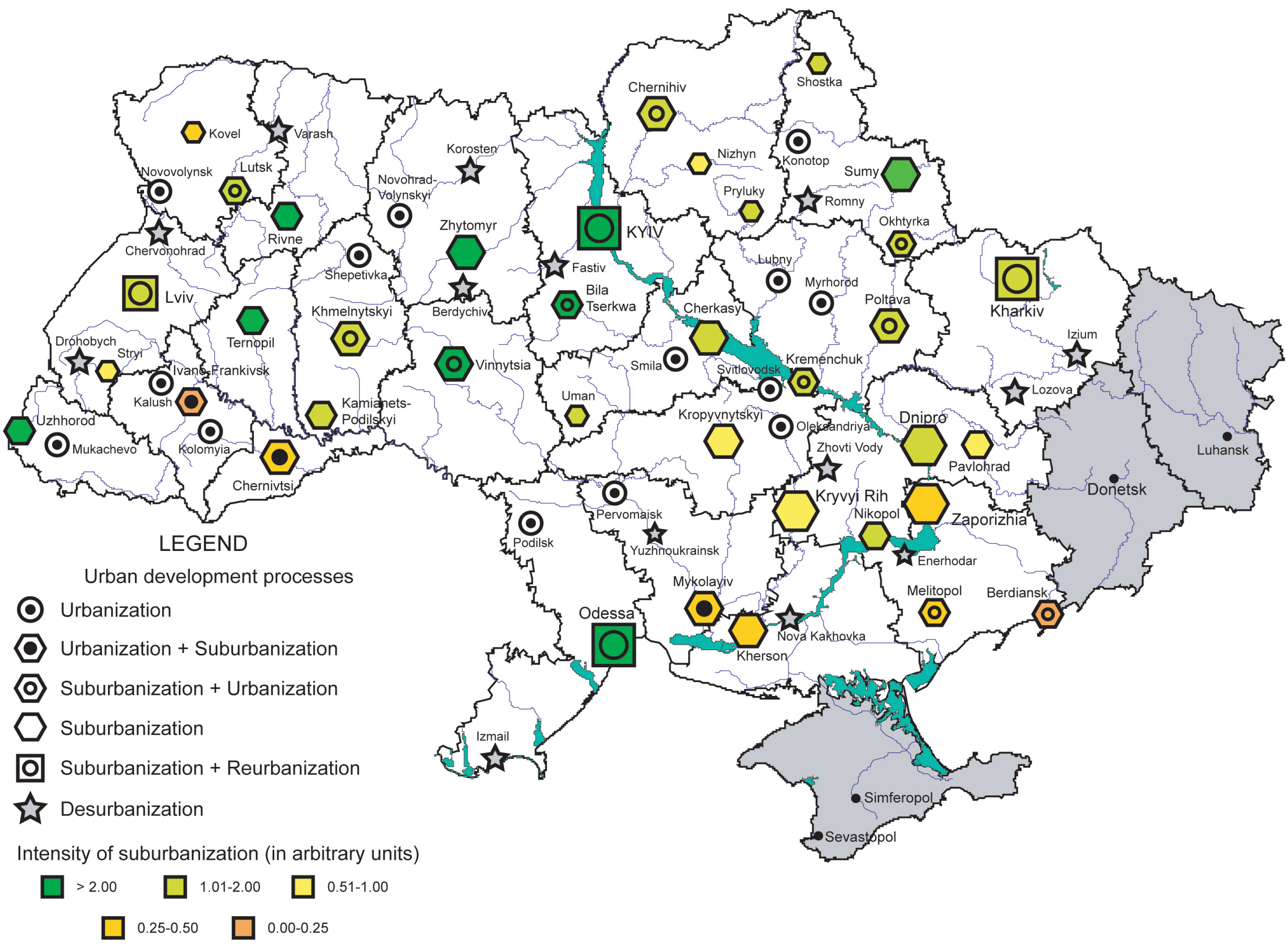


**Fig. 3** Urban development processes and intensity of suburbanization.

**Tab. 1** Correspondence between groups of cities and stages of urban evolution.

| Group/subgroup | Processes | Stage of urban evolution (Gibbs 1963) | Stage of urban evolution (Klaasen et al. 1981; van den Berg et al. 1982) |
|---|---|---|---|
| 1 | Urbanization | Rapid urban growth | Urbanization |
| 2.1 | Urbanization + suburbanization | Urban saturation | |
| 2.2 | Suburbanization + urbanization | Suburbanization | Suburbanization |
| 2.3 | Suburbanization + reurbanization | Suburbanization | Reurbanization |
| 3 | Suburbanization | Suburbanization?<br>Deconcentration? | Suburbanization?<br>Desurbanization? |
| 4 | Desurbanization | Deconcentration | Desurbanization |

be rather parallel variants of the urban evolution: the first option could be typical of cities with more intensive economic development, while the second may be typical for the less dynamic cities. Finally, it is possible that the cities from subgroup 2.2 are "activated" (due to the renovation of economic development) cities from group 3, and therefore over time and under favourable conditions, they may even move to subgroup 2.3.

From a theoretical point of view, suburbanization should be followed by desurbanization (or deconcentration), and desurbanization, in turn, should be followed by reurbanization. However, direct transition from suburbanization to reurbanization is also possible. Available empirical data are insufficient for a clear conclusion; however, the last option is very probable for the cities from subgroup 2.3 as their suburbia obviously never stopped to grow since the collapse of Soviet Union.

Finally, cities from group 4 show typical pattern of absolute or relative desurbanization and, in some cases, deconcentration. Predominantly, these cities are small or medium-sized (maximal population recorded is around 78,000), therefore, taking into account established relationship between population and probability of peri-urban growth, it is very possible that they entered this phase directly from the stage of urbanization or, in some cases, from the stage of the early suburbanization.

Figure 3 shows main processes taking place in Ukrainian cities / urban regions, as well as intensity of suburbanization I.

Table 1 demonstrates the correspondence between groups and subgroups of Ukrainian cities, relevant processes, and stage of urban evolution.

Sufficiently high correlation between identified stages of urban evolution in Ukraine with common theoretical models indicates that urban dynamics in Ukraine is rather evolutionary than involutionary and therefore similar to other Eastern European countries. However, in post-Soviet conditions, urban development stages and their sequences in urban regions may be different from those prescribed by theory: some stages may be skipped or repeated. The collapse of Soviet Union in 1991 launched the "natural" process of urban evolution, but simultaneously caused large-scale restructuring of the economy, having a critical role for the development of individual cities. Therefore, different urban development trajectories are possible depending on economic and social environment. In crisis conditions, the city at any stage of evolution may experience sudden migration outflow and over time possibly retrace to normal development. Cities may transit to reurbanization avoiding the stage of desurbanization. Kliuiko (2013) has a point when asserts that deurbanization and post-suburbanization are selective processes: some of the cities attract population, investment, jobs, and therefore progress further in their evolution, others, even neighbouring, fall behind. Consequently, Ukrainian experience supports for Ouředníček (2007): urban region do develop in certain stages and possibly cycles, but their set and sequence cannot be strictly determined. Also, this findings correspond to conclusions of Mezentsev and Havryliuk (2015) about the so-called "model gap" in urban dynamics in Ukraine, manifesting by inconsequent passing of stages due to the influence of political, socio-economic, and demographic factors.

## 6. Conclusions

Suburbanization process in Ukraine is far more widespread than one may imagine based on existing scientific literature. Migration growth of peri-urban area comparing with main city and hinterland is observed in the majority of studied cities, including all cities with population over 100,000. Simultaneously, some of the largest cities possibly entered the stage of postsuburban reurbanization. In general, larger population of the main city means greater probability of suburbanization and larger intensity of this process. However, in Ukraine, migration growth of the main city appears to be better marker of urban economic development than migration growth of suburbia. These findings put a question about the factual mechanisms of migration dynamics in peri-urban areas. The study revealed a high correlation between identified stages of urban evolution and common theoretical models. However, some stages of urban evolution and migration patterns are rather debatable and may essentially differ from their classical Western prototypes. Individual and regional specifics and irregularities are also clearly visible.

Verification of these conclusions can be done through further in-depth researches of certain cases with special focus on differentiation between classical suburbanization, urban ruralization and rural urbanization, investigation of internal spatial structure of peri-urban areas and specification of qualitative differences of suburban areas in cities of different sizes and functional profiles. It seems yielding to compare Ukrainian cases with their equivalents from the other CEE countries and define in this manner common and individual aspects of urban evolution in total and suburbanization in particular.

## Acknowledgements

This research was made within the framework of scientific project No 16BP050-02 "Spatial Transformation in Ukraine: Models of Urban Modernization and Planning" funded by the Ministry of Education and Science of Ukraine. My best thanks also go to Dr. Kostyantyn Mezentsev, Dr. Anatoliy Melnychuk, and Dr. Olena Denysenko who helped with methodological and conceptual advice in the preparation of this paper.

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# PARTICIPATORY RESEARCH IN COMMUNITY DEVELOPMENT: A CASE STUDY OF CREATING CULTURAL TOURISM PRODUCTS

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**ABSTRACT**

Although participatory research can be an improvement over conventional research, there is a lack of self-critique and self-reflection by scholars. The aim of this paper was to develop a method of participatory research in human geography based on a case study of the local community. We evaluated the positive and negative aspects of carrying out participatory research in community development from the local community and academic points of view. The participatory method was used in a rural local community in Slovenia, where cultural values were identified as an alternative developmental source. The method was presented in detail in three steps: 1) knowledge acquisition, 2) knowledge synthesis, 3) knowledge implementation and evaluation. The results yielded important social impacts, some economic and cultural impacts, and no significant ecological impacts. The paper discusses the impacts of conducting such research on the local community. It recognizes that, if the community is actively engaged in research, outcomes are likely to be matched to its needs and expectations. We discussed scholars' bias towards economic aspects of community development and the fact that ignoring local knowledge may result in the failure of developmental initiatives. There is a need for more accurate and unbiased critical assessment of long-term impacts of carrying out participatory research. We believe we avoided two common traps of participatory research: regarding the positivist critique, this method offers sufficient scientific vigour and could be reproduced in similar communities; regarding the post-structural critique, personally committing stakeholders towards implementation and legitimising all social groups to overcome intrinsic power relations within the community. We concluded that participatory methods are important for obtaining local knowledge that complements traditional academic research.

**Keywords:** participatory research, community development, local knowledge, cultural tourism, participatory method, human geography

Received 14 March 2017; Accepted 4 July 2017; Published online 25 August 2017

## 1. Introduction

### 1.1 Why conduct participatory research?

Participatory research (PR) in geography is often merely a phrase used in theoretical literature, but there have been few attempts especially in Central and Eastern European human geography to develop and present appropriate methods of conducting it. Researchers have to rediscover participatory methods fragmented across disciplines, which are generally not adapted to geographical research. One of the issues that motivated us was also our own experience, that a top-down process may alienate local community members and fail to capture locally important factors (Fraser et al. 2006). This is especially true for community planning projects. Evidence shows that top-down initiatives achieve statistically significantly lower results on the accomplishment of local communities' goals and end-user satisfaction (Larrison 2002). Secondly, keeping scholarly debates exclusively in the scholarly domain and not involving citizens in the process is increasingly understood as unacceptable (Robinson et al. 2014) because the public can help to transfer academic theories into practice. Finally, although PR 'often represents a vast improvement on conventional modes of research' there is a lack of self-critique and self-reflection by social geographers (Pain 2004: 660).

Robinson (1996: 127) gives a heavy critique of 'many social scientists that have left a rather tatty and shameful record in the communities of their research by objectivizing people, their lives and cultures'. In contrast, PR means engaging local communities and people in the processes, structures, spaces, and decisions that affect their lives in order to achieve sustainable outcomes in their own terms (Kindon 2010). An important difference from traditional research is that PR combines scholarly research with community participation. For PR the research process is as important as the scholarly findings themselves. This is why some writers mention it as part of a larger movement toward more openness in academia, because researchers are now working 'with' more than 'on' (DeLyser and Sui 2014). Especially in social geography, PR contributes to community projects and not only 'produces' research findings, but also educates and trains residents, non-academics, and NGOs in order to revitalize local communities (Pain 2004). Minkler and Wallerstain (2008: 6) emphasise that PR is not a research method per se but an 'orientation to research', because the methodological context is more important than the actual methods used. The methodological context usually involves a distinct

https://doi.org/10.14712/23361980.2017.13
Bole, D. – Šmid Hribar, M .– Pipan, P. (2017): Participatory research in community development: A case study of creating cultural tourism products
AUC Geographica, 52, No. 2, pp. 164–175

attitude on the researchers' part and blurs the distinction between who does the studying and who is studied.

The roots of PR can be traced back to developmental projects from over fifty years ago that dealt with ethnic, racial, poverty issues. They draw on Kurt Lewin's problem-solving research model of planning, action, and investigating the results of those actions. They try to carry out focused research to challenge power relations within communities in order to benefit the local community (Minkler and Wallerstain 2008). According to Racadio et al. (2014: 50), community-based PR originates from the 'Southern' tradition of 'action research', wherein researchers believe that their role is to support and educate the community, but that the transformative change has to come from the community itself. In contrast, the 'Northern' tradition emphasises co-participation of researchers in institutional settings, such as schools and workplaces. There they can jointly solve problems on a small scale and thus affect their own lives. Going even further, Tress et al. (2005: 487) define the participatory process as a project in which academic and non-academic participants exchange knowledge in a parallel process to try to solve a problem, but 'the focus is not on the integration of the different knowledge cultures to create new knowledge and theory'.

In short, the distinction between participatory and traditional research is in the purpose of conducting it. The aim of PR is usually not only to gain new knowledge for the researcher but also to aid the local community with developmental, social and other issues. Bergold and Thomas (2012: 2) state that PR is the 'convergence of two perspectives – that of science and of practice. In the best case, both sides benefit from the research processes.'

### 1.2 Criticism of participatory research

Despite its wide application, PR has its limitations and has been criticised. The traditional positivist critique is mostly related to its 'unscientific' and 'informal' approach. Neef (2003) sums up the main positivist stances of PR. It is methodologically weak since there is a lack of scientific vigour. Participatory methods do not have the same degree of method formalisation as traditional methods and are not open to the same academic scrutiny and validations. Results of PR seem to produce single case studies that are not usually valid outside of its specific territorial context. Low control of environment and the lack of objectivity due to personal over-involvement are also problematic for positivist critics. They see the weakness of the PR ad-hoc approach, where most of the study is done in cycles with temporary reports, methodologies and frameworks. This may be considered as lacking scientific discipline and is regarded of low academic interest (Kock et al. 1997). Cook and Kothari (2001) also warn of the danger of 'romanticising' local knowledge gained by PR and lack of its critical assessment.

The latest PR critique is influenced by post-structural approaches (see Cook and Kothari 2001; Cameron and Gibson 2005; Kesby 2007; McCartan et al. 2012). They argue that although PR may grant an alternative view on another world, it is fraught with a range of relationships that require constant negotiation and self-reflection. The public and formal character of PR events, further reinforce local power relations rather than reversing them. Neef (2003) warns of the danger of being too naive about internal power structures in the community when applying participatory approaches to research and development. He thinks that most PR exercises pay insufficient attention to the community heterogeneity, differentiations by gender, ethnicity, social position … 'It is necessary to acknowledge that there is not just one 'local reality', but a myriad of positions, interests and needs' (Neef 2003: 492). This implies that not all participants have equal knowledge about reality, nor the means, tools and skills to represent it. Kesby (2007) also criticizes the inability of most PR projects to expand beyond their specific spatial context and thinks that they should seek transformation not just at the local scale but also at the global scale of struggle for social justice.

### 1.3 Objectives of the paper

We want to test the words of Bergold and Thomas (2012) of scientists and local communities co-producing new knowledge that has benefits for both of them. The purpose of this paper is primarily to develop and present a PR method in human geography based on a case study of a local community. Thus, we present a PR method in which the main goal was to encourage development by promoting and creating cultural tourism activities. We wish to contribute to the development of PR in geography, or 'methodological pluralism', which is vital for the discipline's development (Barnes 2011; DeLyser and Sui 2014). We want to see if it is possible to incorporate science and local communities in PR. Second, we want to evaluate the pros and cons of performing PR in community development in contrast to 'classic' top-down research in human geography, for the local community and scholars alike. We want to test the thesis that PR offers short-term and long-term socioeconomic benefits to the local community (in our case development of new cultural and tourism products) and gives researchers the opportunity to discover new local knowledge. Third, we wish to evaluate how successful was our PR method in the context of avoiding most frequent critical traps being attributed to PR.

## 2. Method description

Our method is based on the theoretical and practical research done in various disciplines. Theoretically we relied on the work of Checkoway (1994), who presented core concepts for community change, especially the power of 'getting organized', which is the key process of community change. In shaping our concept of PR we took other studies as a starting point (Buchecker et al. 2003; Kasemir et al. 2003; Golobič and Marušič 2007), but in practice our method came into being largely as an organic process, whereby we adhered to the following principles used in other studies (Checkoway 1994; Checkoway and Richards-Schuster 1999; Bergold and Thomas 2012):

– Researchers are merely guides, moderators, in the best case, advisors, if the local participants request this of us.
– The stakeholders are directly included in the research and are not merely observers that are 'asked for their opinion'.
– Autonomy, whereby stakeholders are given a chance to voice their concerns and ideas and are listened to, so that they take pride in a policy or program.

Research was carried out throughout 2012 and 2013. Before explaining the method, we briefly introduce the territorial setting of the case-study area and the 'tool' or resource that was used to spark new development. Both are important for understanding the context of conducting PR.

### 2.1 Background of the case-study area: Why development by participation?

The case-study area is a small, rural local settlement community called Črni Vrh on the fringe of Idrija Municipality, which has 650 inhabitants and is located in a hilly area in western Slovenia. Local community has in total 1370 inhabitants in nine settlements. Actively involved in PR on a voluntary basis were fifty-nine non-researchers (or 5% of all inhabitants) of three largest settlements: Črni vrh (675), Zadlog (278) and Predgriže (164). Although this is a rural area, the majority of inhabitants work in industry because there are two successful and global industrial plants in the nearby municipal centre, Idrija. Thus, unemployment is not currently a problem, but the municipal strategy has long sought freedom from employment 'dependence' in the industrial sector. It seeks to promote other economic activities and thus increase local resilience from the perspective of employment prospects (Pipan 2013). A high dependence on two major enterprises results in a low level of self-employment, a monostructural orientation, and a lack of entrepreneurship in the community. The poorly represented service sector offers limited job opportunities for highly-educated people from fields other than engineering (Urbanc et al. 2012). The problem lies especially in the outmigration of well-educated young people, who do not see their future in the industrial sector, and the resulting aging of the local population (Fridl and Repolusk 2010; Kladnik 2010).

Paradoxically, the success of Fordist industry in this community also represents its major weak point because it is stagnating socially and economically. It is also vulnerable because industrial production in the globalized world can be outsourced momentarily. However, the local population currently lacks the motivation and the skills for a systemic approach towards new social and economic development sparked by tourism. This condition is 'a space for action' for conducting PR because there is a need to activate the passive local community and seek transformative change. PR is ideal for communities that need to reinvent themselves in the post-Fordist reality and find new development impulses because it is place- and context-specific, bringing local conditions and local knowledge to the fore (Pain 2004).

### 2.2 The tool: local development through cultural tourism

We focused on the development of cultural tourism, which is recognized and managed by the local community itself and offers diversification to the local economy, creates added value, and strengthens community resilience. Participation is very important because the development of tourism can pose a threat to the local inhabitants. Especially if the activities and investors 'come from outside the community' and are merely interested in making a profit, which has more the effect of a nuisance than a benefit to the local community (Horáková 2013). Properly managed cultural heritage can be instrumental in enhancing social inclusion, developing intercultural dialogue, shaping the identity of a given territory, improving the quality of the environment, providing social cohesion, stimulating the development of tourism, creating jobs, and enhancing the investment climate (Bole et al. 2013; Dümcke and Gnedovsky 2013: 7). Although heritage and its preservation have long been regarded as being in opposition to economic development, they are now increasingly seen as effective partners in community development (Loulanski 2006). Apart from the anthropological notion of culture, there has been less attention devoted to the functional interpretation of culture; that is, the analysis of how cultural production and the valorisation of cultural resources may foster economic development (Saccone and Bertacchini 2011).

The integration of culture as an 'alternative' community developmental source is a concept that has also proved useful in other studies (MacDonald and Jolliffe 2003; Marková and Boruta 2012; Šmid Hribar and Ledinek Lozej 2013; Gorlach et al. 2014). In the development strategy of this area, culture-led development is recognized as a tool of new development and of moving away from heavy economic dependence on industrial production. In the past, the study area was known for its crafts and tourism between the two world wars and an important fact is that it is very close to the Idrija mercury mine, which is on the UNESCO World Heritage List. Culture and tourism have been identified as endogenous potentials in development strategies in this area, but these traditional top-down initiatives have been poorly received and have not yielded visible results (Nared et al. 2011, 2013).

Due to methodological reasons, we decided to use the term cultural values. The term heritage signifies something that was or can be inherited, whereas value originates in the verb "to value," which refers to defining, establishing, ascribing, acknowledging value, and thus addresses the relationship between a group or an individual and a specific cultural element. For the purpose of this study, we developed a definition of cultural values with development potential. 'Cultural values are various tangible and intangible elements and individual natural elements of cultural significance and local origin that are identified by the stakeholders and have economic, social, ecological or cultural development potential. The development importance of a specific cultural value co-depends on the utility, compatibility, and scope of development potential' (Šmid Hribar et al. 2012).

### 2.3 Participatory research method in three steps

*Step 1: Knowledge acquisition*

In this step we identified the community's cultural values that were able to be transformed into tourism products and made the first contact with the community. This step can be summarized by the following phases:

- Conducting a traditional survey and community observation;
- Stakeholder analysis;
- First contact: locals voice their opinion of cultural tourism products.

Knowledge of the selected area represents the start of a long-term process and Golobič and Marušič (2007: 996) described this initial process as to 'obtain the knowledge possessed by people living in the area – "raw" local knowledge and information, uninfluenced by experts, local opinion leaders, or mutual communication'. This is a preparatory phase for the real participatory research. It is required to uncover the social and political structures that could later affect the research. In this phase we inventoried all official registries and documents in which the policy and research focus was from the past few decades. This phase proved to be important because we assessed local conditions, entered into the community, and identified decision-makers and local leaders.

The second phase is relatively straightforward. Goal-driven research demands that a broad array of people and organizations be involved from the very start of the process and, as Checkoway puts it, they are a 'central tenet of community change' (1994: 12). Main stakeholders were the local residents. They are regarded as caretakers of their culture and they are the ones that benefit the most from its development. Information about research activities and local involvement was publicized through local conventional media and social media, although personal contact proved to be the most efficient way of ensuring broad representation of individuals. In our experience, the most significant stakeholder group were the young and the elderly, and identification of these stakeholders was an ongoing process throughout the project. For the young communication by electronic means was sufficient, while we had to made personal visits to the elderly population in order to inform them about the project and make possible their eventual participation. A snowball effect happened, where at each meeting stakeholders themselves continually identified new individuals and groups that were personally invited to participate. Some of the stakeholders eventually became 'agents of change': individuals that emerge spontaneously and facilitate the research with their voluntary commitment (Checkoway 1994). The second type of stakeholders – institutional and political actors – were easier to identify. In addition to local politicians, we invited representatives of all institutions (i.e., museums, societies, and development organizations) that had been identified in the previous phase. In order to follow a bottom-up approach it is important that public officials or heritage experts abandon their usual role of 'decision-makers'. We found it more effective to define their role as advisors serving only to steer the process, rather than taking over the process from the most important actors, the local community. The result was a heterogeneous mix of participants: workers at factories, young unemployed, retired factory workers, some farmers and hospitality workers (tourist farms) and representatives of the public sector.

The third phase is the most crucial and already involves participatory techniques, such as Open Space technology and World Café. In the workshop with stakeholders identified in phase two, we gave them the following task: to point out the cultural values that represent their local community and could become potential tourism products. Our role was merely to facilitate this brainstorming process and to answer potential questions from an expert view. In a lively discussion they pointed out twenty-two cultural values that they believed to have developmental potential. At the end of the workshop we asked them to rank these values according to their priorities, interests, and feasibility. Six cultural products out of the twenty-two values were selected to go into the next phase. The goal of such ranking in the participatory process is to explain and emphasize the priorities of local stakeholders, meaning that their voices should not only be heard but also acted upon. This phase conveyed a wealth of new knowledge for researchers. We learned about previously unknown forms of intangible cultural heritage and we gained precious insight into the local social structure and local opinion leaders. This would have been hard to achieve through conventional research.

*Step 2: Knowledge synthesis*

This part of the method is the most time-consuming and involves designing cultural tourism products. It can be explained by two phases:

- Taking responsibility for implementation;
- Getting organized and planning.

The first phase requires active participation of local stakeholders, giving them the power to interact and accept the possibility that they could be changed by this process. For the six cultural products identified in the knowledge acquisition step, we held one workshop and invited all the stakeholders involved in Step 1. By using brainstorming techniques, the goal was to suggest actions on how to turn the six ideas into six cultural tourism products; to specify the goals, potential outcomes, and end results for each idea separately. An important part of this joint workshop was at the end, when we asked them to decide which of the six ideas they wished to engage with further and assume responsibility for its implementation. They were not limited to only one idea and most of them decided they would work on two or more. Some decided that they did not wish to actively participate anymore.

The second phase was planning step-by-step activities for implementing cultural tourism products. The researchers' role was to facilitate and maintain structure; that is, to establish working rules and phases. Selecting an appropriate strategy is therefore central to community change. We used the technique called the Logical Framework Approach (LFA), which is an interactive set of tools for project management and fostering project performance (Walsch 2000). This meant that we carried out six separate workshops, one for each cultural tourism product envisioned, with the end goal of creating the final design plan for these cultural tourism products. Using the LFA technique, the researchers and local stakeholders negotiated short- and long-term objectives, expected outputs, and results already in the first phase. The second phase focused on operational aspects of creating tourism products, which included the following:

- Breaking the activities into manageable tasks;
- Clarifying the sequence, interdependence, and 'connectivity' of tasks;
- Specifying the duration and start and end dates of tasks;
- Assigning responsibilities for tasks.

At the end of each of the six tourism product workshops an 'application form' was completed that summarized the goals, concepts, and individuals taking responsibility for it.

*Step 3: Implementation and evaluation*

For the researchers this was the final step, and it represented a transition from an active to a more passive form of involvement. Our role as 'community organizers' ceased and the local community took the implementation process further through each responsible person appointed in step 2. Still, we can distinguish two research phases:

- Providing expert support for implementing cultural tourism products;
- Evaluation of completed projects.

After the matrix for designing cultural tourism products was finished in step 2, we had no active role in the implementation of the tourism products and we were merely observers of the process only acting if we were asked to. For instance, one of the cultural tourism projects involved reviving the tradition of flax farming and producing souvenirs from it. The population had the necessary tools, arable land, and workforce, but lacked the knowledge and skills. Therefore, we arranged an exchange between residents of our local community and those of the Peio Valley (Trentino, Italy), who showed them all phases of working flax and gave them flaxseed.

The last phase was evaluation of the completed projects of all cultural tourism packages. In the case of short-term objectives, this involves checking whether the tasks and milestones had been completed and whether new cultural tourism services exist. The more difficult part is to evaluate long-term impacts, which involve wider and more profound social, cultural, and economic effects on the community; this is important for attaining our second research objective. We made post-hoc interviews with those stakeholders responsible for tourist packages four years after the project ended for us in 2017. We made an informative matrix of the observed social, economic, ecological, and cultural impacts on the community for each tourist product developed (see Table 2), established in our previous paper (Šmid Hribar et al. 2015). This matrix is based on community observation at workshops and three non-structured post-hoc interviews with community members responsible for implementation of four active cultural tourism products.

## 3. Results

The factual information regarding the method's application in the local community is presented in Table 1. The design plans of six cultural tourism products and partial implementation of four of them was the most important result for the local community. Our second objective was to evaluate the long-term socioeconomic impacts on the local community. Due to the methodological and temporal limitations discussed in step 3, we were able to assess the observed social, economic, ecological, and cultural impacts of each of the six tourism products (Table 2). We observed important social impacts, some economic and cultural impacts, and no significant ecological impacts on the community.

## 4. Discussion

### 4.1 Critical reflections on participatory research for the community

The PR results confirm that it can engage local communities in order to achieve 'sustainable outcomes' on their own terms, as stated by Kindon (2010). However, at the outset the researchers and some of local community officials were heavily orientated towards additional jobs and income creation as primary goals. Yet our impact evaluation (Table 2) shows that over the course

**Tab. 1** Results table of conducting participatory research in the Črni Vrh local community, Slovenia.

| Research phases | Results of each step and phase |
|---|---|
| Knowledge acquisition | |
| Phase 1: survey | – Detailed inventory (status, usage, problems, etc.) of fifty tangible cultural heritage items, one intangible cultural heritage item and one tourist hiking trail;<br>– Assessment of twenty local and regional documents on tourism, development, and culture and heritage protection; |
| Phase 2: stakeholder analysis | – 127 stakeholders identified |
| Phase 3: first confrontation | – Twenty-two potential cultural tourism products identified;<br>– Six cultural tourism products selected for implementation |
| Knowledge synthesis | |
| Phase 1: taking responsibility | – Six workshops for the selected tourism products for setting objectives and designing services and activities;<br>– Fifty-nine stakeholders (thirty-nine individuals and eighteen from public institutions) taking responsibility for implementation |
| Phase 2: planning action plan matrixes for six tourism products | – Stargazing;<br>– Flax farming and processing;<br>– Trnovo cross-country ski marathon;<br>– Matuckar ethnographic trail;<br>– Narrow gauge railway;<br>– Collection of WWI and WWII items |
| Implementation and evaluation | |
| Phase 1: providing support for implementation | – Partial implementation of four cultural tourism products (flax farming and processing, Trnovo cross-country ski marathon, Matuckar ethnographic trail, collection of WWI and WWII items);<br>– Two exchanges of local communities (Črni Vrh, Slovenia and Peio Valley, Italy) |
| Phase 2: evaluation | – Matrix of the developmental impacts for six tourism products |

of the two-year process there has been little impact on economic development. Additional income was created for individuals that were already employed (for example, in the case of a private museum with a collection of WWI and WWII items), but no full-time jobs were created. The owner manages and offers interpretations of the collection to visitors on a volunteer basis and accepts only donations. The other two products (narrow gauge railway and flax production) developed in a similar way while three tourist products cased in active development (Trnovo cross-country marathon due to lack of snow, stargazing and Matuckar ethnographic trail due to lack of interest). This could prove that structural changes (i.e., moving from an industrial to a service-oriented economy) is a process involving deeper changes in forms, identities, practices, and mental constructs, as claimed by Cruickshank et al. (2013), and it cannot be achieved in a short time frame.

On the other hand, we observed strong positive social impacts of PR on intergenerational and intercultural dialogue in the community. Younger residents were included in identifying, designing, and implementing tourist packages and they eventually took responsibility for implementing three tourism products (flax production, the narrow gauge railway, and the ethnographic trail), but they were also assisted by older residents. At the meetings there was also a renewed feeling of strengthened social ties or 'community-building' by connecting previously alienated various stakeholders: especially civil society (represented by individuals, NGOs, and volunteer associations) with the public sector. For instance, those involved in flax production connected with municipality run Geopark Idrija and created "GeoFood" brand offering culinary products made of flax (bread, oil, etc.). The variety of tourism products selected enabled the cooperation of very different social groups with different interests and age groups, contributing to strengthening the social dimension of sustainable development, a feature that is often overlooked in discussions of sustainability. Post-hoc interviews confirm that the main positive impact for community members was in social networking or as one person said: 'We needed someone to come from the outside, from the Capital, to wake us up a little'. Thus our results lead us to agree with Lehtonen (2004), who highlighted the importance of social capital in sustainable development: weaving new social relations and facilitating new actions of actors in those relations are at the core of social capital definitions.

The cultural impacts observed were also positive. Our research also verifies what Richards (2007: 295) has described, that culture and heritage tourism 'can be the means for learning and exploring one's own environment, and hopefully awaking interest in other cultures too'. Developing tourism products renewed local interest

**Tab. 2** Observed impacts for each of the developed tourist products on the community (+ high impact, 0 medium impact, – negligible impact).

| | Economic development | | | | | | Social development | | | | | | | Ecological development | | | | Cultural development | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | New job position | New company | Sustainable tourism | Use of local materials | Encouraging new business approaches | Encouraging tourist activities | Strengthening local identity | Educational role/knowledge transfer | Developing new knowledge | Place promotion | Integration of vulnerable social groups | Intergenerational dialogue | Community empowerment | Preservation of existing ecosystems | Maintaining the complexity and stability of ecosystems | Supporting local organic food production | Erosion prevention | Inspiration and encouragement for artistic Expressing | Active involvement, personal experience | Personal identification | Spiritual experience |
| Stargazing | – | – | 0 | 0 | 0 | 0 | – | + | 0 | + | – | + | – | – | – | – | – | 0 | + | – | + |
| Flax production and processing | – | – | + | + | + | + | + | + | + | + | + | + | + | + | + | 0 | – | + | + | + | + |
| Trnovo cross-country marathon | – | – | 0 | 0 | 0 | 0 | + | + | – | + | – | + | + | – | – | – | – | – | + | + | 0 |
| Matuckar ethnographic trail | – | – | 0 | + | – | – | + | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – | – | – | 0 | 0 | 0 |
| Narrow gauge railway | – | – | + | + | 0 | + | 0 | + | 0 | + | 0 | + | + | – | 0 | – | 0 | – | + | 0 | – |
| Collection of WWI and WWII items | 0 | 0 | + | + | 0 | + | + | + | 0 | 0 | 0 | + | + | – | – | – | – | – | 0 | 0 | + |

in preservation, interpretation, and knowledge of the locals' own cultural heritage. Flax processing and making flax products was a strong tradition in this community until the Second World War, when it started to decline. By 'packaging' flax production into a tourism product, we promoted new interest in learning this old knowledge when participants started to search for old processing tools and original flax seeds within their community. This cultural tourism product eventually evolved further into an educational product because activities were included in the Europe-wide educational initiative 'European Cultural Heritage Days'. According to Scheyvens' framework for determining impacts of tourism on local communities (1999), we also observed positive social and psychological empowerment. This is because the local community recognized the uniqueness and worth of their culture and later developed more confidence to look for further education and training opportunities. The involvement of individuals, especially young people and in some cases entire families, working together to create tourism products also enhanced their sense of social cohesion, which corresponds to the concept of social empowerment. We think that the key action that enabled positive results for the local community was in step 2 where local participants took personal responsibility for implementation of activities. This dissolved traditional power relations, because in the past the municipality with institutions (museum, developmental agency) was the driving force behind developmental and tourism projects. By putting the power of implementation into the hands of individuals, a real sense of empowerment was felt. We created a context of enjoyment and friendship among participants, an observed effect also in some other PR exercises (Cameron and Gibson 2005). We took particular attention to the participant heterogeneity and diversity. We found out that for participants the project meant different things: the younger generation was more interested in participating for future economic benefits and ready to 'take things into their own hands'. The elderly and the employed factory workers saw their participation more as a volunteering exercise for community-building and social revival of their town. We ensured them that both motives are completely legitimate and not excluding to avoid what Cook and Kothari (2001) refer to as 'power imposition' of one group over another. In our case, this proved effective enough and finally both groups worked alongside.

Although we can conclude that the local community mostly benefited from this PR, we must also acknowledge that this was limited to social and cultural developmental aspects. One probable reason for the 'failure' to attain tangible economic and environmental results could be that the cultural tourism products implemented are only the start of reinventing the community with new developments across longer time dimensions. Some products that are currently marketed on a volunteer basis could eventually evolve into permanent employment-offering ventures. An additional reason could be that the current economic situation with stable and full employment in the industrial sector limits the desire for new full-time ventures in tourism. Generally, people in the community are more interested in socializing and volunteer work rather than finding additional employment or profit. On the other hand, this is a positive outcome of the research and we agree with Mahjabeen et al. (2009), who write that, if the community is actively engaged in planning, plans are likely to be matched with their needs, interests, and expectations.

We find that PR could potentially be useful for drafting community-led local development programmes (such as the LEADER funds in the EU) where participation could ensure the better realisation of funds and the matching of local interests. This type of PR could also be useful in other post-socialist communities, where due to specific socioeconomic development some research found a general apathy of people regarding public participation and civil involvement (Greenberg 2010; Coman and Tomini 2014).

### 4.2 Critical reflections on participatory research for researchers

The first research benefit that we point out must be identification and prioritization of the community's needs, which once again points to the need for transdisciplinary research, based on intense integration of academics and non-academics. Such approach would enrich the participation process and contribute to solving challenges within the community. Our premise at the start of this study was that the community desired new development matched by their needs and terms. However, we were unaware that, for them, 'development' did not mean new jobs or extra income, but socializing, developing community links, and creating small-scale cultural experiences. This fact was also observed by Blangy et al. (2008) and Mair (2015), and it forces us to rethink our concepts of community development and geographers' fixation merely on its economic aspects. PR has the potential to grow into transdisciplinary research if scholars from various academic field integrate local stakeholders as early as the design step instead of merely inviting them to participate, as stated by Tress et al. (2005). As they comment, this would lead to transdisciplinary research with the involvement of researchers from various unrelated disciplines as well as non-academic participants working from the beginning and trying to create new knowledge and theory.

The second research benefit gained by conducting PR is obtaining new local knowledge. This is best illustrated in the knowledge-acquisition phase of our research, when we conducted a survey of cultural heritage based on research literature, official registries, and fieldwork. The list of 'cultural values predominantly included tangible cultural heritage, especially secular architecture (e.g., old homesteads), sacred architecture (e.g., churches, chapels, crosses), and memorial heritage (Šmid Hribar et al. 2015). After the local community gave its own input the list was completely different, with the focus shifting to intangible heritage, with economic practices and skills in the foreground (Table 3). This proves that the local people have a very different yet detailed understanding of local culture and its role in new development interventions. This also implies that not including local perceptions and knowledge may result in the failure of developmental initiatives.

There is still a need for more accurate and unbiased assessments of the long-term impacts of PR. Because it is being created largely through practice, 'the theory often takes a back seat', as stressed by Wiewel et al. (2012), and critical assessment is lacking. Another danger is 'romanticizing local knowledge' into development practice and assuming its inherent superiority over knowledge produced by traditional academic research, as pointed out by Smith (2011). In our opinion, the participatory method presented here could be useful in order to draw local knowledge into decisions that affect people of local communities so that they can achieve sustainable outcomes on their own terms. However, this local knowledge should be investigated just as critically as any other form of knowledge.

If we evaluate our method, we can conclude that we have avoided some critiques attributed to PR. The main positivist stance is that PR uses unreplicable methods. We believe our method is concrete and structured and does not differ in scientific vigour from other human/social empirical procedures. By including well-known techniques (LFA: logical framework approach, open space and word café workshops) this method is replicable yet still flexible enough for other territorial contexts. By clearly defining the PR process at the very start as a mutual symbiosis with benefits both for scientists and the local community, the overall confusion about the research goal is less likely.

We are less confident about our method being used in larger local communities. Post-structural criticism of negative power effects of participation or 'group tyranny' is a threat especially for larger communities. In our case, the local community was small and it was possible to reach out to all social groups, even disadvantaged ones such as the unemployed youth and the elderly. In practice, this meant that we communicated with them personally or via phones and ensured their participation. For us the key moment was when we identified 'gatekeepers' or trusted

**Tab. 3** Numbers of cultural heritage items identified in various steps of the knowledge acquisition phase. The last column provides items selected by public participation for having the best developmental potential.

| | | **1st phase / official registries and literature** | **2nd phase / participation of locals** | **Items selected in the workshop** |
|---|---|---|---|---|
| Tangible cultural heritage | Archaeological heritage | 1 | 0 | |
| | Secular architectural heritage | 12 | 6 | Windmill, dugouts and bunkers, Tominc House, renovation of a blacksmith's workshop, tower on Point Peak (*Špičasti vrh*), flax-drying device |
| | Religious architectural heritage | 23 | 0 | |
| | Religious-secular architectural heritage | 0 | 0 | |
| | Memorial heritage | 13 | 1 | Military cemetery in Črni Vrh |
| | Garden architectural heritage | 0 | 0 | |
| | Settlement heritage | 1 | 0 | |
| | Cultural landscape | 0 | 0 | |
| | Historical landscape | 0 | 0 | |
| Intangible cultural heritage | Oral tradition and folk literature | 0 | 0 | |
| | Performances | 0 | 1 | Singing activity |
| | Custom and habits | 0 | 0 | |
| | Knowledge of the environment | 0 | 2 | Stargazing, pond |
| | Economic practice | 1 | 6 | Flax production and processing, making a charcoal pile, restoration of Idrija lace, teamsters, lime kilns, homemade baked goods |
| Other | Hiking trails | 1 | 4 | Trnovo cross-country marathon, Matuckar Trail, narrow gauge railway line in connection with hiking, Via Alpina hiking trail |
| | Natural heritage with cultural significance | 0 | 1 | Ivanjšek linden tree |
| | Item collection | 0 | 1 | Collection of WWI and WWII items |

Source: Šmid Hribar et al. 2015

individuals that reached out to certain social groups and in effect represented them at workshops. It is difficult to imagine this kind of face-to-face communication to take place in larger urban environments since trust-building process is time consuming. We agree with Kesby (2007: 2827) who said that understanding that participation is 'enmashed in power rather free from it is very helpful to the practice of participation'. There were indices in our case study that the local government (especially municipality officials) wanted to use this PR project to legitimise their top-down actions in the Črni Vrh community. We had to make clear to them that they had to abandon their usual decision-making role. This caused some friction at first, but on the other hand, this 'relinquishment' of power enabled real participation of other stakeholders later on. This also implies that researchers have to be aware of those 'power issues' and to recognise and deal with them as soon as they arise.

Of course, we cannot claim that repetition of our PR method would lead to similar results in other territories, which is an objective limitation of doing this kind of research. The method may be the same, but the context, issues and interests within the local community may be very different. However, we think that by iterating the guiding steps of our method (knowledge acquisition, knowledge synthesis, implementation and evaluation) and by using standardised participatory techniques (LFA, Open Café) we can achieve a more rigorous PR. That is a prerequisite to develop more general knowledge and theories, which would address global socioeconomic issues and needs of communities in the future.

## 5. Conclusion

Participatory research in human geography can be applied and can achieve substantial results, not only to gain new knowledge but also for the benefit of communities involved. Building a trusting and respectful relationship among stakeholders and scholars is the key ingredient. Only after this climate of trust has been developed does the PR method become feasible. Abandoning the traditional role of researchers as 'wise outsiders' and assuming the role of 'enabling facilitators' proved helpful in achieving positive results as well as putting the power of implementation into their hands. We found out that personal communication with certain social groups as the unemployed youth or the elderly and finding the (informal) representatives of those groups (gatekeepers) is of outmost importance to ensure heterogeneity of local community and to avoid the 'tyranny' of the majority. An important but unexpected finding in this study was the realization that in the short term local stakeholders, especially older people, see the strengthening of social cohesion and local identity as more important than economic gain. The next finding is that the participatory process also has the power to bring together previously alienated stakeholders in the community, especially the public sector with private operators, individuals, and even academia. This finding can also be the start of a new kind of research: from participatory to transdisciplinary research. It is important that researchers from various academic groups begin working with non academics from the very beginning, working to shape (or 'co-design') the study in line with their needs. We conclude that the participatory process in communities is a long-term process and that it does not offer immediate economic impacts. It requires knowhow and the investment of significant human capital, whereby heterogeneous local and public stakeholders, experts, and even international participants can work together. We believe that this method offers sufficient scientific vigour and could be reproduced in similar smaller communities. However, it is questionable if it can bring positive results in larger communities, where personal contact between scientists and the community is harder to make and maintain. However, the long-term results, largely in the form of social empowerment for the communities and a way for researchers to obtain embedded local knowledge, can be very rewarding any may open up new research questions.

## Acknowledgements

This article was prepared as part of the project SY_CULTour (Synergy of Culture and Tourism: Utilization of Cultural Potentials in Less-Favoured Rural Areas) and was co-financed by the Southeast Europe Transnational Cooperation Program. We would like to thank the people of Črni Vrh local community, the Peio Ecomuseum, the Municipality of Idrija, the anonymous reviewers and Federico Bigaran for their helpful contributions to the project.

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# MONITORING WATER QUALITY PARAMETERS OF LAKE KORONIA BY MEANS OF LONG TIME-SERIES MULTISPECTRAL SATELLITE IMAGES

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**ABSTRACT**

In this study, a comprehensive 30-year (1984–2016) water quality parameter database for Lake Koronia – one of the most important Ramsar wetlands of Greece – was compiled from Landsat imagery. The reliability of the data was evaluated by comparing water Quality Element (QE) values computed from Landsat data against *in situ* data. Water quality algorithms developed from previous studies, specifically for the determination of Water Temperature and pH, were applied to Landsat images. In addition, Water Depth, as along with the distribution of floating vegetation and cyanobacterial blooms, were mapped. The performed comprehensive analysis posed certain questions regarding the applicability of single empirical models across multi-temporal, multi-sensor datasets, towards the accurate prediction of key water quality indicators for shallow inland systems. Overall, this assessment demonstrates that despite some limitations, satellite imagery can provide an accurate means of obtaining comprehensive spatial and temporal coverage of key water quality characteristics.

**Keywords:** Lake Koronia, Landsat, water quality, Water Framework Directive

Received 20 March 2017; Accepted 14 September 2017; Published online 4 October 2017

## 1. Introduction

Both natural and artificial lakes supply over 90% of Earth's liquid surface freshwater, facilitating human activities and economic development, while serving as essential habitats for a large variety of biota. Lake ecological status affects their value as drinking water reservoirs for irrigation, fishery and recreation. For this reason, the alleviation of the degradation of surface and ground waters was one of the main objectives outlined in the Water Framework Directive (WFD, 2000/60/E.C.). WFD aims at protecting surface waters of Member-States and ensuring that there shall be no further deterioration in water quality, structure and function of aquatic ecosystems. Concerning lake ecosystems, the WFD specifies Quality Elements (QE, Annex V) for the classification of ecological status, which include biological and hydro-morphological elements, as well as ancillary chemical and physico-chemical information.

In many cases, lake water quality data either do not exist or are very limited. Only a small percentage of lakes are regularly monitored by *in situ* measurements and, as a result, historical water quality data are sparse, sporadically collected or non-consistent for most lakes. Nevertheless, a fundamental part of this "missing" information has been recorded in the historical archives of satellite imagery, enabling the extraction of some historical water quality information over lakes, which have never been retrieved before.

Coupled with advanced processing methods and improved sensor capabilities, an increasing development in remote sensing of lake quality parameters has been observed during the last decades (Dekker and Seyhan 1988; Fuller and Minnerick 2007; Bresciani et al. 2011). Satellite remote sensing can be used to map and monitor QE, with the aim of reconstructing their historical variation and assessing their distribution and patterns.

Inland natural waters are complex physical–chemical–biological systems, including living and non-living elements that may be present in aqueous solutions or in aqueous suspensions (Younos & Parece 2015). Lake water contains numerous dissolved mineral salts and organic substances, suspensions of solid organic and inorganic particles, including various live microorganisms, as well as gas bubbles and oil droplets. The water components participate directly in the interactions with solar radiation in that they absorb or scatter photons. Also, they may participate in diverse geochemical and biological functions, for example, in photosynthesis, which regulates the circulation of matter in these ecosystems and affects the concentrations of most of the optically active water components. Four components of aquatic ecosystems are the major cause of light absorption in natural waters (Kirk 2013): a) Water, b) Photosynthetic biota (phytoplankton and Macrophytes), c) Tripton, and d) Dissolved pigments. Remote sensing sensors measure the water leaving radiance (*Lu*), which is the upwelling radiance emerging from the water surface, as well as the radiance derived from scattering processes in the atmosphere. The estimation of water quality derived from remote sensing measurements is based on water quality parameters that have an effect on water-leaving radiance. The absorption and scattering

https://doi.org/10.14712/23361980.2017.14
Perivolioti, T.-M. – Mouratidis, A. – Bobori, D. – Doxani, G. – Terzopoulos, D. (2017): Monitoring water quality parameters of Lake Koronia by means of long time-series multispectral satellite images
AUC Geographica, 52, No. 2, pp. 176–188

properties of the medium are described by its inherent optical properties (IOPs).

As some of the lake QE can be determined using remote sensing with a reasonable accuracy, remote sensing techniques may be integrated in the monitoring programs defined by the WFD (Giardino et al. 2007).

The aim of this study was to reconstruct/create a historical lake water quality parameter profile, by adopting a remote sensing time-series approach. The purpose was to monitor lake QE, such as Water Temperature and pH, using multispectral Landsat images from 1984 to 2016. In addition, Water Depth, as well as the distribution of floating vegetation and cyanobacterial blooms were mapped. The remote sensing data were Landsat-5/TM (Thematic Mapper), Landsat-7/ETM (Enhanced Thematic Mapper), Landsat-8/OLI (Operational Land Imager) and Landsat-8/TIRS (Thermal Infrared Sensor) images. The investigation took place over a Ramsar-protected ecosystem, i.e. Lake Koronia, Greece.

Along with mapping the temporal and spatial QE variability of lake Koronia for the past three decades, the results are expected to contribute to: (a) the definition of optimal image processing routines for QE estimation and external calibration procedures based on multispectral satellite images and *in situ* measurements, (b) the assessment of the correlation of water quality parameters with Landsat bands (c) the establishment of procedures that shall allow the compatibility of past satellite information with water quality information derived from future Sentinel-2 data.

## 2. Study area

Lake Koronia (40°41′N, 23°09″E) is the one of two lakes composing the Mygdonia Basin. It is situated 30 km north-east from Thessaloniki (Figure 1), Central Macedonia, northern Greece. Koronia is an elliptic-shaped, shallow, polymictic lake, with a surface of 29 km$^2$.

The wetland of Lake Koronia has a tremendous ecological importance, which has been worldwide recognized. Namely, it is protected by the Directives 79/409/EEC and 92/43/EC, the RAMSAR Convention and is categorized as a Natura 2000 site. It used to be one of the four largest lakes in Greece, occupying an area of 46.2 km$^2$, but in recent years, due to low precipitation and the water over-consumption, it has become an intermittent lake. Hence, Lake Koronia has highly variable hydrologic conditions. This leads to rapid changes in physical and chemical conditions in the lake water column. The regular dry out and re-filling of the lake creates an extreme state of flux which prevents the establishment of stable states observed in more typical lakes (Zalidis et al. 2014).

Overall, Lake Koronia faces a number of serious environmental issues and water management problems, which cause changes to this unique and invaluable ecosystem. The degradation of Lake Koronia is caused, mainly, by inflow pollutants (municipal, industrial, agricultural) and by the overpumping of water for irrigation. The surface water of the lake as well as the groundwater cannot sustain the unsystematic economic growth of the area resulting in water depletion, negative water balance, environmental degradation and very serious economic problems (Mylopoulos et al. 2007).

The water quality of Lake Koronia is monitored by the Management Authority of Lakes Koronia-Volvi (M.A.L.K.V.), which was established in 2002 under Law 3044.

## 3. Data and Methodology

### 3.1 Lake reference data

The spatial and temporal resolution of *in situ* data that have been collected over Lake Koronia during the past decades is limited. For the purposes of this study, *in situ* measurements were performed at three sampling stations in Lake Koronia on 30 November 2015. The location of the sampling points was selected taking into account the adequate spatial coverage of the lake. Two sampling stations were located in medium depth points (Station 1, Station 2) and one sampling station was located in the deepest point (DP) of Lake Koronia (Figure 1).

For the determination of the sampling station coordinates, a handheld Garmin GPSMap76S receiver was used. Concerning the reduction of the location error, the coordinates were determined three times per sampling point and the average value was considered.

The QE Water Temperature (°C), pH and Water Depth (m) were measured just below the lake surface. Oxi 3205, WTW, Dissolved Oxygen (D.O.) meter, including integrated temperature sensor, was used to perform Temperature measurements. For pH measurements a pH meter 3110, WTW was used.

In addition to the field data that were collected on 30 November, *in situ* data of the parameters Temperature and pH, were provided by the M.A.L.K.V. These parameters were monitored monthly from two sampling stations (Akti Analipsis, Vasiloudi) (Figure 1) and as a consequence there was an adequate database of *in situ* estimation that could be used for satellite data calibration/validation. The data that were provided by the M.A.L.K.V. correspond to the period from 27/4/2009 to 2/11/2014. Due to the absence of *in situ* measurements of the QE Secchi Disk Depth and Chl*a*, field data available from relevant publications were used (Michaloudi et al. 2009; Michaloudi et al. 2012; Moustaka-Gouni et al. 2012). Michaloudi et al. (2009) and Michaloudi et al. (2012) present values of physical and chemical parameters in water samples from the deepest point of Lake Koronia during the period from March 2003 to December 2004. Moustaka-Gouni et al. (2012) present phytoplankton data that were collected in years 2003–2007 and 2009–2011.

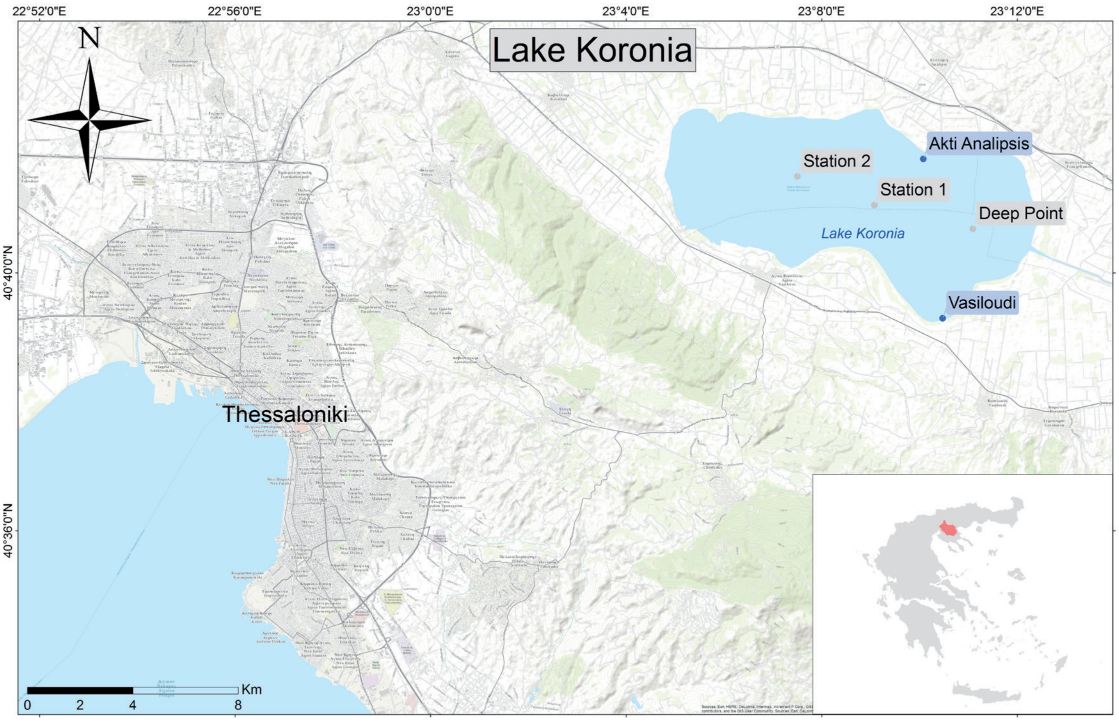


**Fig. 1** Map of Lake Koronia and the locations of the M.A.L.K.V. sampling stations (Blue), as well as the sampling points used in sampling procedures on November 30 (Grey), in Lake Koronia.

Field data collected within one day of the satellite overpass yield the best calibration results, while the larger number of field measurements with a longer time window offsets some of the loss of correlation (Kloiber et al. 2002). All field data used in this study were collected within ± 1 day of a Landsat image acquisition date. The *in situ* data collection on 30 November 2015 was carried out during (within few hours from) the Landsat-8 overpass.

### 3.2 Satellite data

The satellite data (Level 1T) of Landsat-5/TM, Landsat-7/ETM+, Landsat-8/OLI and Landsat-8/TIRS were used, as these provide the longest consistent temporal record of space-based surface observations. Typically, only two Landsat scenes were required to cover lake Koronia (path/row: 184/32,183/32). Appropriate satellite data were identified using EOLI-SA and USGS Global Visualization Viewer. EOLI-SA's satellite data were provided by ESA (ID: 31068). A total of 715 multispectral satellite images were selected, spanning the period from 1984 to 2016 and fulfilling the following criteria: (a) less than 70% overall cloud coverage and (b) low cloud coverage over the study area.

### 3.3 Image pre-processing

Digital Numbers (DNs) from image data were converted to spectral radiance ($L_\lambda$) and top-of-atmosphere (TOA) reflectance ($\rho_P$) (Chander and Markham 2003; Zanter 2015).

Attempts to obtain Surface Reflectance from the initial DN values were made using software developed specifically for this purpose, i.e. LEDAPS (Masek et al. 2013) for Landsat-5 and -7 images. However, a strong discordance of the processed images was observed when compared against *in situ* data and this observation resulted in the exclusion of the surface reflectance products for further calculations, in favor of TOA-reflectance values, which were derived solely by algorithmic processes developed by the authors, according to the officially designated mathematical models previously mentioned.

#### *3.3.1 Geometric correction*

Two cloud-free Landsat/TM images (path: 183/184), were geometrically corrected using a) Ground Control Points/GCPs, which were available from Mouratidis et al. (2010) and b) a processed 3-arcsecond SRTM (Data Version 4.1) DEM, available from CGIAR-CSI (Jarvis et al. 2006). The GCPs were collected in 2008 (Mouratidis et al. 2010). With the intention of facilitating GCP identification, the selected Landsat/TM images were acquired in 2008 as well. The selected images had minimum or no cloud coverage. To obtain adequate accuracy during geometric correction, GCPs were evenly distributed in the image. The process was concluded, when accuracy better than 0.5 pixel (15 m) had been achieved. These two orthorectified Landsat/TM images were subsequently used, in order to georeference, via an automatic image-to-image co-registration, some of the other downloaded Landsat images which were characterized by geolocation errors of several km.

*3.3.2 Area of Interest*

All Landsat images were cropped, setting as Area of Interest (AOI) a rectangle area surrounding Lake Koronia and considering its maximum extend, as depicted on topographical maps of the ’70s and ’80s (Hellenic Military Geographical Service/HMGS, scale 1:50,000). The selected AOI was chosen to be as small as possible, in order to facilitate further processing of the long time-series. Images, in which the boundary of the Lake was not clearly visible, were excluded from further processing.

*3.3.3 Water-only image*

Subsequently, water-only images were created, in order to delineate the water body and extract water features. In addition, water-only data were used for the creation of pixel level condition maps of Lake Koronia. In order to extract a water-only image from each AOI Landsat image subset, from 1984 to 2016, a function was developed in MATLAB. Firstly, a broad separation of lake water from land areas was performed using Normalized Difference Water Index (NDWI) (McFeeters 1996):

$$\frac{\mathrm{GREEN} - \mathrm{NIR}}{\mathrm{GREEN} + \mathrm{NIR}}$$

where GREEN is the band that includes reflected green light and NIR is the reflected near-infrared radiation. Positive values pertain to water features and zero or negative values to vegetation and soil.

As the optical properties of Lake Koronia vary both temporally and spatially, the water extraction cannot be based on one standardized cut-off value/threshold (usually value 0 for NDWI). Consequently, the isolation of water pixels was accomplished by performing k-means unsupervised classification, to all NDWI Landsat images. In order to avoid the inclusion of separate water areas on the same image, which may not belong to Lake Koronia, but are probably randomly distributed small-scale water occurrences on the images, a neighbor expansion method was implemented using MATLAB. By employing k-means classification, the cut-off value for each NDWI image was fluctuating around zero (but not being necessarily exactly equal to zero) – thus taking into account the variation of the optical properties of Lake Koronia. Furthermore, the neighbor expansion method that resembles a typical Floodfill algorithm (Godse and Godse 2008) was used to isolate the main body of Lake Koronia, before the next processing step.

### 3.4 Water quality parameters extraction from multispectral satellite data

The estimation of lake QE was based on the application of an empirical or statistical approach for remote sensing data analysis. Algorithms, statistically modelling relations between combinations of spectral bands and measured water QE, as well as procedures developed from previous studies, were applied to radiometrically calibrated pixels of Lake Koronia.

Parameters such as pH, Water Temperature, Lake Coverage, Water Depth were selected as primary representative characteristics of the status of Lake Koronia. The selection of the parameters was based on their contribution as key-variables to lake water quality.

Temperature was estimated from all Landsat images, using the respective thermal bands and applying the calibration methods described in NASA (1999), Chander and Markham (2003) and Zanter (2015). Linear regression analysis was performed for the complete, unified time series of the temperatures of Lake Koronia.

In order to measure the pH of Lake Koronia the following formula was used (Khattab and Merkel 2014):

$$\mathrm{pH} = 9.738 - 0.084 \cdot \mathrm{SWIR}$$

where SWIR corresponds to the DN value of the short-wave infrared band.

Furthermore, the distribution of aquatic vegetation and Cyanobacterial blooms was mapped. Pixels were classified into four groups: (a) floating vegetation, (b) submerged vegetation, (c) lake water and (d) Cyanobacterial bloom zones. For the separation of the “mask pixels” into four classes, a three-step process was followed. Firstly, water pixels and vegetation pixels were distinguished using Floating Algae Index (FAI), modified for Landsat images (Oyama et al. 2015):

$$\mathrm{FAI} = R_{rc,B4} - \left[ R_{rc,B3} + (R_{rc,B5} - R_{rc,B3}) \cdot \frac{(\lambda_{B4} - \lambda_{B3})}{(\lambda_{B5} - \lambda_{B3})} \right]$$

where $\lambda_{Bi}$ is the center wavelength for the $i$-th band of Landsat-5.

FAI pixels were sorted according to class value size using k-means classification. The pixels in the class with higher FAI values were classified as vegetation.

Afterwards, vegetation pixels, which were distinguished using FAI, were separated into submerged and floating vegetation, using the blue/green band ratio (Cho 2007). Since the presence of vegetation in water alters the relationship between depth and reflectance in blue and green bands, it was experimentally shown that a ratio between bands Blue and Green provided the highest degree of correlation with vegetation cover in shallow waters. Vegetation pixels were separated into two classes, using k-means classification. Lower Blue/Green reflectance ratio pixel values were classified as SAV, while higher values where categorized as floating vegetation.

Finally, aquatic Macrophytes and cyanobacterial blooms were detected using the Normalized Difference Water Index $(\mathrm{NDWI})_{4,5}$ (Oyama et al. 2015).

$$\mathrm{NDWI}_{4,5} \frac{(\rho_{NIR} - \rho_{SWIR})}{(\rho_{NIR} - \rho_{SWIR})}$$

where $(\rho_{NIR}, \rho_{SWIR})$ is the reflectance of near-infrared and short-wave infrared bands

An $\mathrm{NDWI}_{4,5}$ threshold of 0.63 is shown to syccessfully detect aquatic Macrophytes when their concentration in

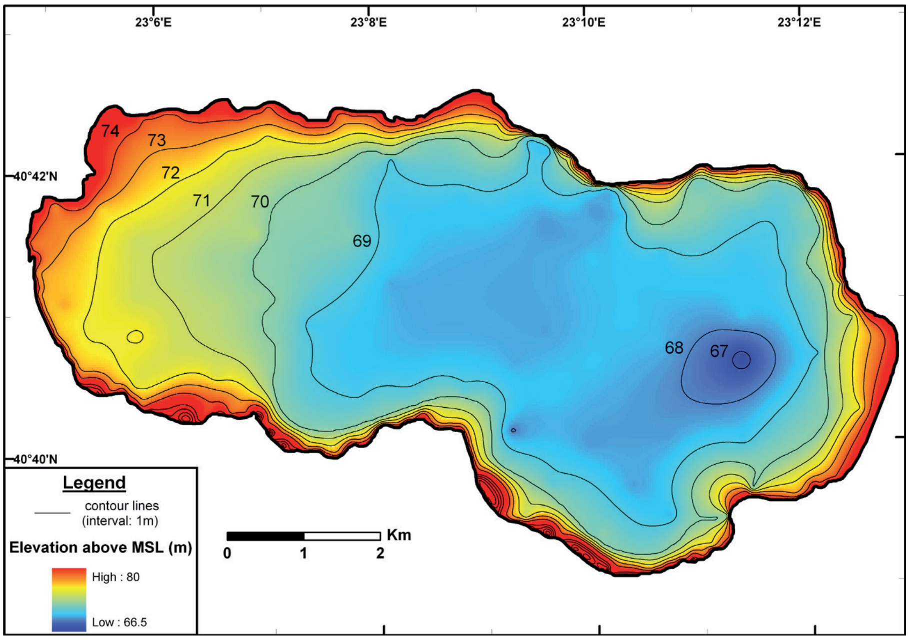


**Fig. 2** Digital elevation model of the Lake Koronia bottom.

the lake is larger than 10% (Oyama et al. 2015). Consequently, the floating vegetation pixels were separated in two classes using k-means classification with respect to $NDWI_{4,5}$ values. The class with values larger than 0.63 corresponds to Cyanobacterial blooms, whereas the class with lower values corresponds to aquatic Macrophytes.

An analytic band-ratio depth model was determined by following the model described in Stumpf et al. (2003). Electromagnetic radiation intensity is attenuated exponentially as a function of optical depth along the emission path, as well as the wavelength of the radiation. Different wavelengths are attenuated at different levels, as a result of variable water absorption. As a consequence, it is expected that the ratio of the logarithms of reflectance in two different bands shall vary linearly with depth over water. This provides a method for the calculation of the lakebed terrain.

The logarithmic ratio used to study the bathymetric characteristics of Lake Koronia was blue/red. The ratio values were calculated for the pixels of the water area of Lake Koronia (22/5/1986) and a digital elevation model (Figure 2) of the lake bottom, created from 1:50,000 scaled maps of the HMGS from the '70s, was used to extract bathymetric data for the same pixels. A linear model was fitted in value pairs of reflectance logarithm ratios and depths, and the model parameters were recorded. The model was applied on the same satellite image to map the reliability of the model with respect to the original depths. The errors were found to lie within reasonable ranges, in comparison, for example, to Tang and Pradhan (2015).

The QE variations over the sampling stations in pairs of time-series from *in situ* data and data derived from Landsat satellites were calculated. The satellite-derived values were calculated as 3 × 3 averages over the stations' matching pixels.

## 4. Results and Discussion

### 4.1 Satellite data validation using *in situ* measurements

The values of the hydromorphological and physico-chemical parameters, measured on 30 November, 2015 at three sampling stations are given in Table 1. No significant deviations were observed between the values at the three sampling stations for most of the parameters. This could be attributed to the relatively intense weather conditions at the time of the sampling, which were characterized by relatively strong winds and water currents, causing significant relocations of large water masses, thus smoothing out the parameter variations over the lake area.

These values appear to have large deviations from the corresponding parameter values calculated from the Landsat-8 satellite image of the same day (Table 2). This was, in part, expected, due to the very prominent cloud artifact coverage of the image during the day of overpass. Furthermore, it should be noted that this disagreement between the values may be coincidental, owing to a multitude of sources of error in both the *in situ* and the satellite data and processing procedures, and that a larger number of both *in situ* and satellite measurements have to be available to avoid circumstantial inaccuracies. Comparison of a larger data series should enable the delineation of a more definitive, reliable and conclusive picture of the relation between pH values acquired through these different methodologies. Apart from that, it was impossible to calculate temperature data because the TIRS instrument of the Landsat-8 satellite was not functional during that time period, since on November 1, 2015, the Thermal Infrared Sensor (TIRS) experienced an anomalous condition related to the instrument's ability to accurately measure the location of the Scene Select Mechanism (SSM).

**Tab. 1** Physical and chemical composition of *in situ* water samples (Station 1, Station 2, Deep Point) from Lake Koronia on 30 November 2015.

| | | Sampling Station | | |
|---|---|---|---|---|
| **Parameters** | **Units** | **Station 1** | **Station 2** | **DP** |
| pH | | 8.54 | 8.54 | 8.52 |
| **Temperature** | °C | 11.1 | 11.1 | 11.3 |
| **Water Depth** | m | 2.3 | 2.1 | 2.2 |

**Tab. 2** Comparison between *in situ* and satellite-derived data for pH.

| | Sampling Station | | | | | |
|---|---|---|---|---|---|---|
| **Parameters** | **Station 1** | | **Station 2** | | **DP** | |
| | *In situ* | Satellite measurements | *In situ* | Satellite measurements | *In situ* | Satellite measurements |
| pH | 8.54 | 5.4 | 8.54 | 5.8 | 8.52 | 5.81 |


**Fig. 3** pH (1) and Water Temperature (2) variations over the two sampling stations (Vasiloudi, Akti Analipsis) in pairs of time-series (2009–2014) from *in situ* data and data derived from suitable radiometric calibration of the thermal bands of the Landsat satellites.

Figure 3 depicts the temperature and pH variations over the sampling station Akti Analipsis in pairs of time-series from *in situ* data, provided by Management Authority of Lakes Koronia-Volvi, and data derived from suitable radiometric calibration of the suitable bands of the corresponding Landsat satellites. In the case of Landsat-5/TM data, the pH values appear to deviate no more than 1 pH unit. The same limitations with above also apply for this parameter, which means that when the lake water level was relatively low, the station pixels typically refer to dry land, rendering the parameter calculation equations invalid.

In the case of Landsat-7 SLC OFF, the data appears to be scrambled and misleading. This is because, frequently, every few consecutive satellite images, the scan lines of invalid data cover the sampling station pixels, resulting in invalid measurements. The deviations could, also, be attributed to shortcomings of the derived parameter model equation. In the case of Landsat-8, the temporal overlap between the *in situ* and the satellite image derived data is even smaller in duration, primarily because the Landsat-8 mission is very recent in comparison to the data available from the sampling stations. The inconsistency of the data could be, too, attributed to the fact the water level of the lake was lower, often forcing the calculation to take place over very shallow waters.

It is also possible that, because the original equations were developed using Landsat-5 data, discrepancies arise from slight differences in the corresponding sensors of Landsat-7 and Landsat-8 satellites.

The only significant match between *in situ* and satellite-derived temperature values occurred for the sampling station of Akti Analipsis, when using thermal band radiation data from Landsat-5/TM thermal and Landsat-7/ETM+VCID-2 bands. The irregular (negative) values in the figures for the cases of Landsat-7 are attributed to the cases where the sampling station pixels are at a location with invalid satellite data, due to the Landsat-7 SLC malfunction.

The mismatch between the time-series values of Landsat-8 and the *in situ* data could be because of stray light. Since the launch of Landsat-8 in 2013, thermal energy from outside the normal field of view (stray light) has affected the data collected in TIRS Bands 10 and 11. This stray light increases the reported temperature by up to four degrees Kelvin (K) in Band 10 and up to eight K in Band 11. This can vary throughout each scene and depends upon radiance outside the instrument field of view, which users cannot correct in the Landsat Level 1 data product. Band 11 is significantly more contaminated by stray light than Band 10. It is recommended that users refrain from using Band 11 data in quantitative analysis including use of Band 11 in split-window surface temperature retrieval algorithms.

### 4.2 pH

Figure 4 depicts the time-series of satellite-derived average pH values of Lake Koronia. It is easy to distinguish an overall drop in pH in the case of Landsat-5 data over the period of approximately mid-1988 until the early 1990. Similar periods can be seen in Landsat-8 data. The Landsat-8 data appear to be out of place, with relatively unrealistic pH values. This observation once again validates the suspicion that the pH equation favours data from the Landsat-5 satellite. Although Landsat-7 SLC-ON derived data also appear realistic in relation to well-known *in situ* data over the area, data derived from Landsat-7 SLC-OFF images appear to produce distorted pH values. This can be attributed to both the Scan Line Corrector malfunction (as the designated point pixels may contain invalid data in many cases) and the presumed higher "affinity" of the equation model to Landsat-5 data.

Elevated pH values arise when the photosynthetic activity is very high (Scheffer 2004). Three major processes that affect the pH are photosynthesis, respiration, and nitrogen assimilation. The effects of photosynthesis and respiration on the pH depend largely on the carbonate–bicarbonate–carbon dioxide equilibrium (Lampert and Sommer 2007).

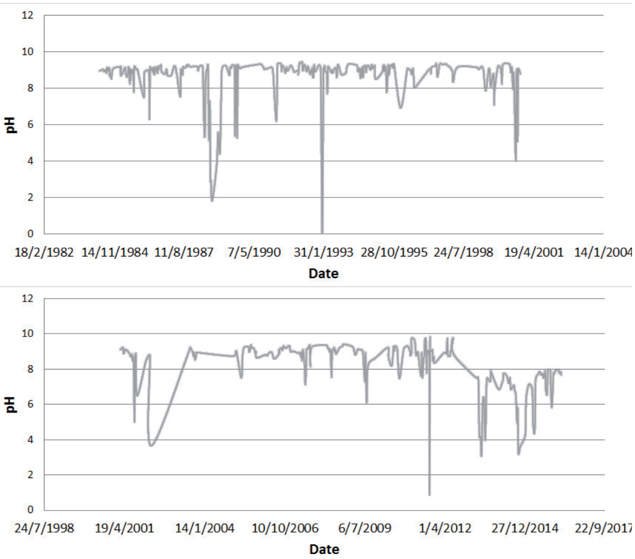


**Fig. 4** The average pH values of Lake Koronia derived from Landsat images (1984–2016).

### 4.3 Temperature

Water surface temperature is the result of the energy balance at the water surface and heat transport mechanisms within the water body. Therefore, knowledge of it is required to characterize processes at the water surface. Figure 5 presents the average temperature time-series of Lake Koronia from satellite image derived data over a period of about 30 years. The seasonal pattern is clearly visible on the charts, with peak temperatures occurring during the summer seasons and minimums in winter seasons.

The temperature of the lake's water presented wide fluctuations over the course of the years, with values in the expected range, from a few degrees under 0 °C up to 25 °C, or even 30 °C. Meterological and climatic factors, including air temperature, cloud cover, and solar radiation, in addition to geomorphometric factors, such as lake surface area and depth, influence surface water temperatures in Lake Koronia. A statistically significant increase trend is observed in the temperature of Lake Koronia in the time interval between 1984 and 2016. The increase corresponds to a coefficient of 0.000422 (+/− 0.00022) per day ($p = 0.00015$), which is equivalent to an increase of about 1.54 (+/− 0.8) °C per 10-years. This can be attributed to the effects of the reduction, up to 90%, of Lake Koronia water volume (Mylopoulos et al. 2007).

A comparison of the Temperature values with data from Bobori (2001) shows a relatively fair accuracy, well within the limits of one standard deviation. In specific, the temperature from 5 stations in a period of two full years (of irregular observations), namely 1989 and 1990, from Bobori (2001) results in an average Temperature value of 16.90 ± 8.2 °C, whereas the corresponding overall average of the lake in the same time period in the current study results in a value of 14.78 ± 8.1 °C.

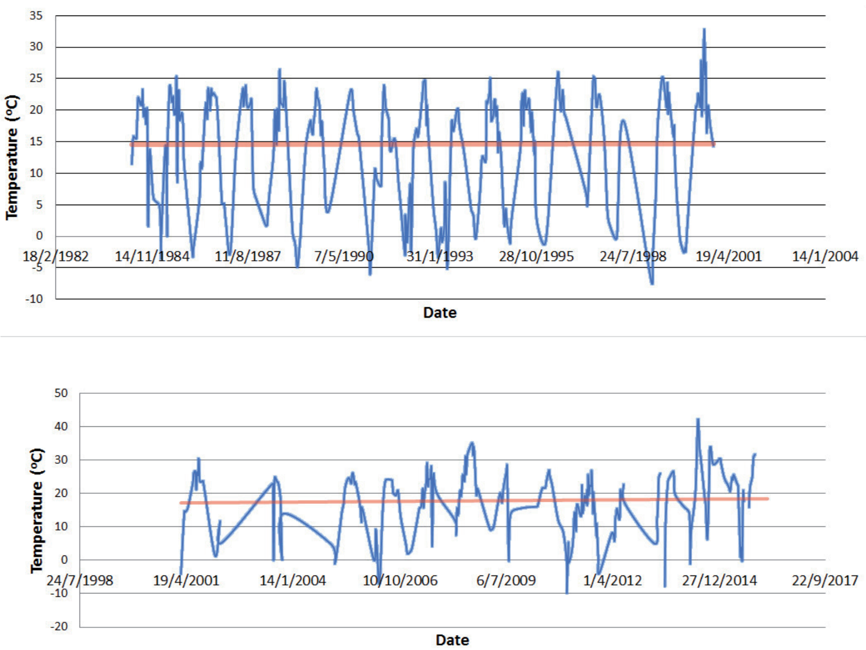


**Fig. 5** The average temperature values of Lake Koronia derived from Landsat images (1984–2016).

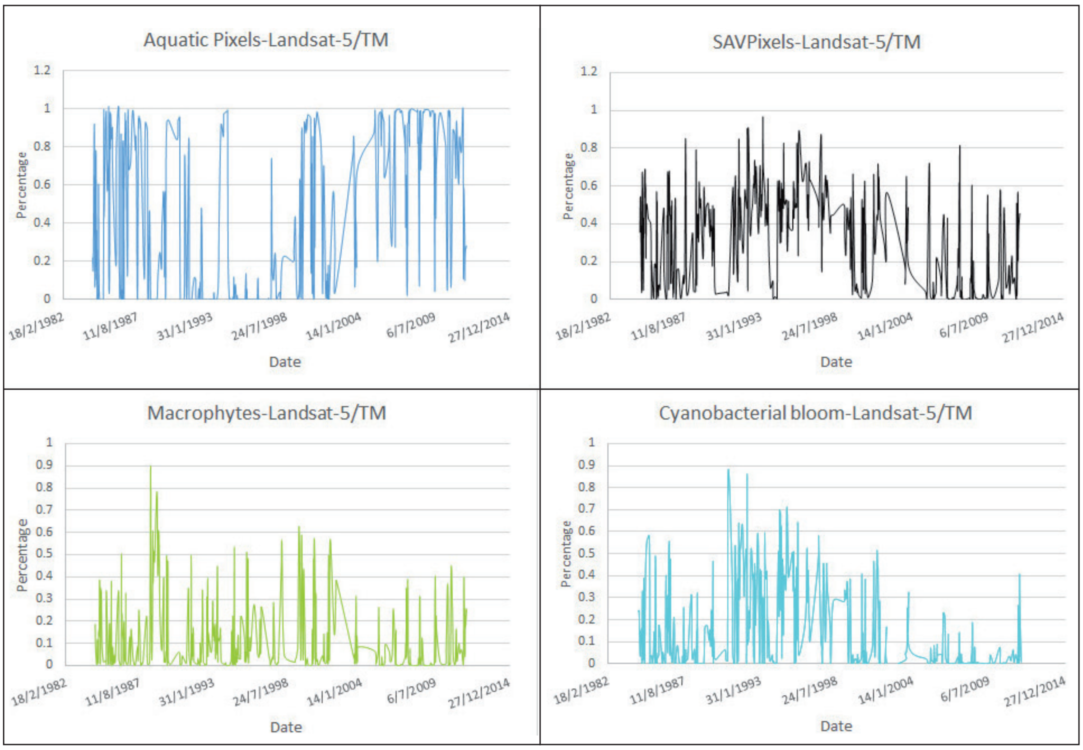


**Fig. 6** The percentages of various coverage types (water, Submerged Aquatic Vegetation, Macrophytes, Cyanobacterial Blooms) of Lake Koronia surface derived from Landsat-5/TM images (1984–2011).

Furthermore, an investigation of Temperature data from Michaloudi et al. (2012) also reveals a fair accordance. An indicative example from Michaloudi et al. (2012) shows an average Temperature value of 24.1 °C in August and September 2003. The Temperature data of the present study resulted in an average Temperature value of 21.84 ± 2.35 °C during the same period.

### 4.4 Lake Coverage

Figure 6 depicts the time-series of the lake pixels as classified into water, SAV, Macrophytes and Cyanobacterial blooms. The data are presented in percentage of pixels of each class with respect to the total of the lake pixels. In general, a strong temporal variation in the 4 categories is apparent from all charts. There are extended time

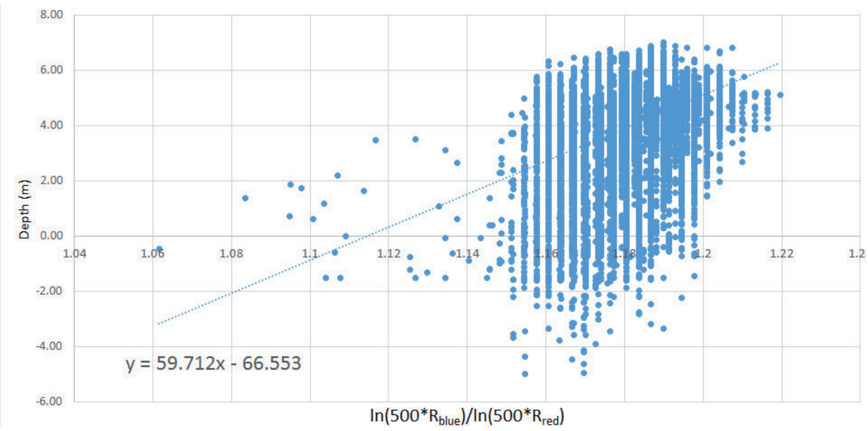


**Fig. 7** Water Depth model of Lake Koronia (22/5/1986).

periods, during which the lake was increasingly covered with either Macrophytes, or Cyanobacterial blooms. An interesting observation is that pixel Macrophytes and Cyanobacteria never appear to covary. This contravariance between the two coverage types can be explained as the two organism species are antagonistic in nature. In the later years, the lake appears to have relatively clear water, with a notable exception between approximately August, 2014 to May, 2015, when there was an increase in Macrophytes coverage and Submerged Aquatic Vegetation. Similar observations can be made from the charts for earlier time periods.

### 4.5 Water Depth

The data plotted are logarithmic ratios (X-axis) against depth values over pixels (Y-axis) (Figure 7). The data pairs used for the fit are about 50,000, which is a very large amount of data for this kind of statistical calculations. Although this can strongly bias the data, it appears on the plot that there is an even balancing-out of relative outliers. The expected trend is effectively captured and the resulting equation can be seen on the plot.

Figure 8 depicts the error map of the extracted bathymetric model referred to in the previous two figures. The values of the lake pixels are calculated as the differences between the pixel 'actual' depth (from the DEM) and the depth calculated using the equation extracted from the log-ratio fitted model. It is encouraging to observe the fair accuracy of the model, as well as the very important pattern of higher errors close to the shores. The latter observation was expected and provides a validation of the model and is attributed to the much smaller difference in electromagnetic radiation attenuation between the two different wavelength bands of blue and red when the 'travelled' water column thickness is smaller. When light travels a larger distance in water, the much higher absorbance of the red band wavelengths in comparison to blue absorbance, due to much faster exponential attenuation of red radiation, creates much more acute differences in the distribution of ratio values, resulting in a higher sensitivity for the model. In simple words, the model can capture a depth difference of 0.5 m between two points much more accurately in deeper waters than in shallower. Furthermore, in shallow waters, the recorded reflectance values are also significantly altered by the optical properties of the bottom of the lake.

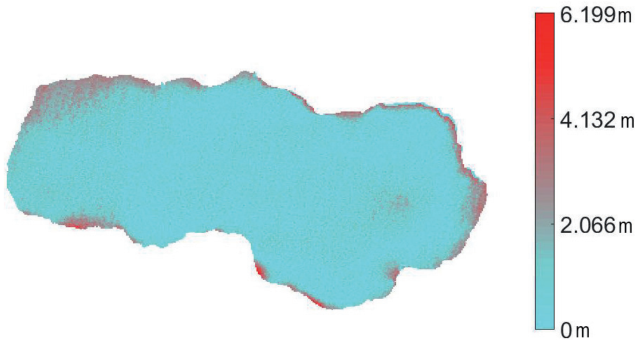


**Fig. 8** The residuals (m) of the lake depth model of 22/5/1986 compared against the bathymetry derived from the used DEM.

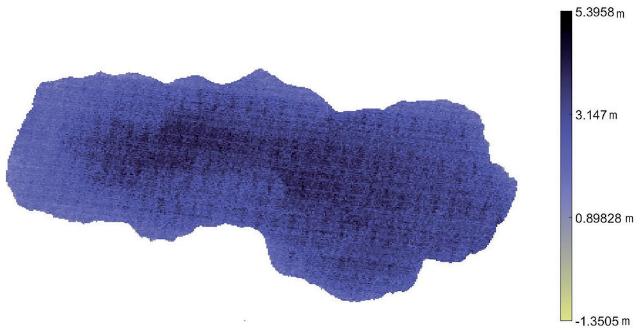


**Fig. 9** Lake Koronia Depth (m) (30/7/1988).

Figure 9 depicts the application of the derived bathymetric model over the lake at a later date, but still relatively close to the date of the satellite image used to estimate the model. In time, it is expected that the bottom of the lake undergoes significant changes in its morphology, due to mass (and biomass) deposition and other reasons. This fact alone is enough to render the bathymetric model valid for a limited time period spanning the temporal proximity of the date of retrieval of the data used for the model fitting. The result appears to provide a bathymetric map of the lake with a fairly satisfactory accuracy, as seen in comparison to the lake bottom DEM used for the extraction of the model.

## 5. Conclusions

### 5.1 General Remarks

Prior to presenting the conclusions of this study, it ought to be noted that the mathematical foundations underlying the mechanics of the models adopted do not bear the same integrity in all cases of parameters, and a similar observation can be made for the physical foundations to an even higher degree. It is nevertheless important to be cautiously optimistic in view of the vast availability and potential of satellite data. Apart from the physics behind the studied parameters, moderation should also guide the statistical interpretations, in the sense that there is not always a clear and definitive meaning behind an apparent correlation. Therefore, the results of this study are in no way conclusive, and extensive cross-validation is necessary prior to adopting a model for wider application.

In this context, the conclusions of this paper are subsequently discussed along two axes, i.e. (a) with respect to the feasibility of extracting reliable water quality parameter values from satellite imagery and (b) regarding the evolution of Lake Koronia, based on the creation and analysis of QE time-series from satellite data.

### 5.2 Model Assessment and Parameter Calculation Feasibility

The notion of feasibility as used henceforth refers to the physical possibility of exploiting the satellite imagery data to obtain a deterministic relation between the optical properties of water and a specific parameter. It is clear that this cannot always be the case. Whenever this is not the case, a relation may still be obtainable but is nevertheless not expected to carry a deterministic meaning, rather it may be valid for purely statistical reasons. Such relations are not expected to be reliable in the long term, in contrast to deterministic ones for feasible parameters. Empirical models specific for the calculation of feasible quality parameters have long term use, while empirical models related with not feasible parameters should be calibrated/validated using *in situ* measurements when the optical properties of the lake change.

Water temperature can be considered as a feasible parameter, as it is directly related to thermal radiation.

A deviation of the pH of water from its neutral value in a natural system is always brought about by the existence of one or more substances, acidic or basic in chemical nature. Each substance may have a specific light absorption spectrum, different to that of another one. Should the spectra have a high degree of overlap, the results on optical properties and reflectance of the various wavelengths are expected to be cumulative, creating a specific optical signature determinable by reflectance. However, this is not always the case. Therefore, the cumulative optical signature will necessarily depend on the concentrations of the strongest of acids or bases that are dissolved in the water and, simultaneously, have dominant EMR absorbance spectra (strong absorption or reflection at various wavelengths). EMR absorbance spectra of such substances may have very diverse presentations. As a result, a significant problem is that the water in natural systems is only slightly acidic or alkaline, which means that small changes in pH may be associated with large changes in optical properties. This renders pH determination a rather precarious methodology. In a simple example, two acid substances with very different absorption spectra might, in suitable concentrations, alter pH in the exact same way in a water solution. Any model "trained" to identify the pH based on EMR reflectance of water in the setting of one substance will fail when the pH change is due to the other substance, due to much different reflectance values. Therefore, pH is hereby considered not feasible as a satellite-image derivable parameter. It must be mentioned, however, that there are cases of natural water bodies that are affected by, more-or-less, the same substances over relatively medium-sized time periods of up to a few decades. Therefore, relatively small pH variations can actually be effectively captured by a model exploiting the reflectance properties of water, as long as the dissolved substance profile does not change significantly in composition.

The Lake Coverage from various types of aquatic vegetation and organisms is based on justified scientific evidence. The physical basis is connected to the natural pigmentation from molecules residing within the various different organisms, such as chlorophyll in aquatic vegetation or phycobiliproteins, such as phycocyanin and phycoerythrin in cyanobacteria. The light absorbance spectra of these pigments are well documented and reflectance in the suitable wavelengths, as well as various band combinations, correlate well with the concentration of vegetation or cyanobacteria. Thus, the lake Coverage is hereby considered a feasible determination.

The model fitting of Water Depth on reflectance data is based on the different properties of the absorption spectrum of clear water in different wavelengths. An important problem arising in this calculation is the maximum depth that can be captured from a model, and the prerequisite that the water be clear. These two facts need to be suitably verified to an adequate degree in order for the model to be able to provide bathymetric data of usable accuracy. Since the mechanics of the model are very vividly explained and consolidated in (Stumpf et al. 2003), the approximation of bathymetric from satellite-image derived data is hereby considered a feasible process with trustworthy results. It must be stated in this point as well that a bathymetric model of whichever, relatively shallow overall, water body is only valid as long as the water remains relatively clear and the surface of the bottom is not heavily affected and deformed. Furthermore, it is clear from the fact that the final model is a single linear equation that acute simplification of reality occurs in the end product (the equation of the log-ratio model). As a result, the model should only be considered a preliminary compaction of bathymetric information, valid for a few years or even decades in the case of clear water and relatively undeformable lakebed.

As concluded by scrutinizing the content of the corresponding articles in literature, the primary concern of this study is to capture possible trends and correlations between a parameter and variations in one or more bands or mathematical band combinations from satellite images of the Landsat satellite missions. It appears that the TOA reflectance (or surface reflectance) is not the only favored measurement for the modeling, as a significant number of papers make extensive use of DN values from raw satellite images.

Although a number of models, such as those applied for the estimation of pH, appear to provide realistic results, it must be noted that there is an irregular intrinsic scaling between DN values from different bands. This can be ascertained by closely following the radiometric calibration procedure, during which DN values are converted to radiances using a pre-designated linear transformation, with different coefficients for each band, as given in the satellite image accompanying metadata files. Because DN values of a band are rescaled and compacted in integer values, the DN pixel value distribution over a specific band does not accurately reflect the actual variation of the optical properties for the various land covers, as does the distribution of true TOA- or surface reflectance values. Because the transformation between DN and radiance values is linear, this turns out to be a minor problem when fitting linear models of parameters on DN values. However, the final statistical coefficients cannot be physically interpreted. It is, of course, clear, that the scaling difference between DN values and radiance values becomes a problem when fitting a nonlinear model on DN values, rather than radiances.

DN values do not directly correspond to a physical quantity and being favorable when probing for a realistic correlation between pixel values from a specific band of a satellite image and the values of a specific parameter appears rather counterintuitive to the author. The statistical basis is even further distorted, when the correlation model involves more than one band from DN pixel values, because DN pixel values follow different scaling for different bands. In spite of all that, however, a number of research articles use DN values, probably because they are easier to access, without having to follow a number of cumbersome preprocessing steps. The corresponding models appear to capture the relation between the DN values and certain parameters with satisfactory accuracy. It is important to state that the equations of these models do not have clear natural interpretations; rather they reflect the variation of patterns exhibited by the data used. On the other hand, models based on reflectance values, such as the aquatic vegetation classification, are more realistic and exhibit a straightforward dependence on certain natural properties of the parameters involved. It can be stated, for example, that the TOA- (or surface) reflectance of a specific piece of land cover (within a pixel) with respect to EMR of a specific wavelength (e.g. TIRS, or VCID bands) is directly associated with some natural properties (correspondingly, the average temperature) of the same piece of land.

The successful retrieval of water quality information from Landsat data depends on the quality of *in situ* measurements that will be used for data calibration/validation. The *in situ* samples collected should be as fully representative as possible of the whole site to be characterized and all precautions should be taken to ensure, as far as possible, that the samples do not undergo any changes in the interval between sampling and analysis. Before any sampling project is devised, it is very important to define the lake structure and to establish the objectives since these are the major factors in determining the position of sampling sites, frequency of sampling, duration of sampling, sampling procedures, subsequent treatment of samples, and analytical requirements. Extensive field data are required in order to enable an accurate comparison of satellite data with actual ground data. One of the very first problems is the spatial divergence between the *in situ* measurements and the satellite remotely sensed data. In order to solve this problem it was suggested to realize limnological transects, where possible, instead of point stations. Another problem is the temporal congruity among all the *in situ* measurements. Sampling *in situ* is a long process and a time gap of several hours may exist between sampling stations. On the contrary, the remotely sensed data collection is instantaneous. A partial solution for the problem was pointed and consisted in organizing more boat-stations, displaced at different locations, and again sampling transects. The recording of some additional, complementary to the *in situ*, data, such as weather conditions and wind speed may be useful for the interpretation of the results derived from satellite data.

### 5.3 The evolution of Lake Koronia

The extreme hydrologic variability of Lake Koronia makes it difficult to predict future trends in the QE values and complicates the development of management strategies that may lead to a healthy and sustainable ecosystem.

The values of the various QE determined in this study by analyzing satellite image data of (Landsat-5/TM, -7/ETM+, -8/OLI) are relatively close to reality for the feasible parameters in general, and clearly appear to follow the patterns of their actual variations in time. In the case of non-feasible parameters, short-term periods of accordance between satellite-derived and *in situ* data have been sporadically observed, although general variation trends are missed in the long term. All parameter models perform more accurately on average, rather than in a point-wise (pixel) approach, mostly because of the inconsistencies in image clarity over specific fixed pixels, which invalidate intermediate images of a timeline and, therefore, values of a time-series.

In the present study, the decrease of the measurement accuracy was caused by:
– Atmospheric effects
– Sensor accuracy: <5%
– Sensor failure (e.g. TIRS)
– Models evaluated in other lakes
– Unclear relationship between parameter and optical properties of the water
– Use of DNs in estimating QE
– Low water level of lake Koronia

Genuine outlier values do occur, however, and may be important indicators of changes in water quality.

As lake ecosystems have integral evolutionary characteristics, parameters (QE) are also interdependent and not fully independent of each other. For a deeper understanding, a more extensive statistical correlation analysis between different time-series would be of utmost importance, in order to monitor the co-evolution and identify highly-specific relevant trends in co-variation. In order to provide a more functional satellite-data facility for the monitoring of, including but not limited to, Lake Koronia, a larger volume of *in situ* measurement data with high consistency would be necessary in order to formulate new models and algorithms based on data extracted from satellite images. In that case M.A.L.K.V will be able to have multiple QE measurements with only a few *in situ* measurements.

## Acknowledgements

Satellite data were provided by the European Space Agency (ESA), after the submission of a proposal (ID: 31068). Presentation of the preliminary results of this study during the ESA Living Planet Symposium 2016 held in Prague, Czechia, was made possible through a European Commission student grant. The assistance of the Management Authority of Lakes Koronia-Volvi in the field operation is greatly appreciated.

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# BALANCED OR UNBALANCED DEVELOPMENT? AN EVALUATION APPROACH TO TOURISM DEVELOPMENT IN SOUTH TRANSDANUBIA, HUNGARY

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**ABSTRACT**

Investigating the effectiveness of regional tourism support is always relevant in tourism research, especially in the European Union. However, in recent decades researchers and regional development actors concentrated predominantly on concrete financial-economic aspects based on the monitoring systems of the European integration. Based on this circumstance, the principal objective of this article is to offer various aspects on the research of the effectiveness of tourism subsidies, employing a spatial-geographical perspective. The article aims to determine whether there is a correlation between the presence of tourism attractions, existing tourism demand, and the regional allocation of the awarded subsidies. An elaborate evaluation approach was applied in a NUTS 2 region of Hungary, South Transdanubia. However, the method can be used in different regional levels as well since it is based on settlement-level data. Another claim of the article is that the demonstrated monitoring aspects can further contribute to a more effective regional policy approach concerning the evaluation of tourism developments.

**Keywords:** tourism development, tourism support, correlation, South Transdanubia, regional development, evaluation method

Received 16 December 2016; Accepted 26 September 2017; Published online 10 October 2017

## 1. Introduction

From the second half of the 20th century, it became evident that one of the engines of world economy and a remarkable development force is tourism (Lew et al. 2008; Meyer 2011; Sánchez-Rivero, Cárdenas-García 2014). Since tourism is made up of processes of a timely and spatial nature, it contributes to the formation of a system of sending and host regions, displaying the unique social-economic and environmental characteristics of the localities (Sharpley 2015; Aubert et al. 2015). It is crucial to stress that the regional connections of tourism and the presence of locality are essential since the majority of tourism attractions are based on the attractions of the region, landscape, or local culture. If this area is coupled with an adequate tourism supply, tourism begins to form spatial processes, since it affects settlement structure, employment, spatial relations or the environment, lifestyle and quality of life (Lew et al. 2008; Hall 2012). Thus, regional analyses employing different perspectives should focus more on the processes of tourism since this branch will influence increasing spaces in the world economy (Cole 2007; Jopp et al. 2010; Viken, Granas 2014). Today, the tourism world market creates a coherent and interdependent system wherein both supply and demand go through significant changes in time and space in terms of quantitative and qualitative aspects and components (Conrady, Buck 2010; Dwyer, Kim 2010; Theobald 2011; von Bergner, Lohmann 2014).

The present study intends to demonstrate a comparative regional (settlement-level) and spatial analysis of the spatial distribution of tourism attractions and products, apparent and statistically detected demand, tourism support and the general development level of settlements. The central question of this survey is whether the correlation between the determined attraction survey, the tourism supply and demand and the regional allocation of tourism support sources is interrelated, or whether we can find anomalies and inappropriate practice in the tourism development processes. Furthermore, the paper discusses the correlation between the general development level of a settlement and of its tourism. All these aspects are investigated in a case study in a NUTS 2 region of Hungary, South Transdanubia.

According to the author's hypothesis, several kinds and levels of correlation will be determined during the investigations. First, it is investigated whether we can find any attractions at a specific location. Second, we need to determine if there is an adequate volume of tourism infrastructure. Third, we investigate if there is any tourism demand detected at the settlement. Correlation may also be demonstrated in most cases between the development level of the settlements and their tourism potentials. This aspect of the research focuses on any correlation between the general development level of a settlement (developed and determined by the Central Statistical Office of Hungary) and the quality and quantity of tourism. A further viewpoint of this research is the examination

https://doi.org/10.14712/23361980.2017.15
Csapó, J. (2017): Balanced or unbalanced development? An evaluation approach to tourism development in South Transdanubia, Hungary
AUC Geographica, 52, No. 2, pp. 189–198

of whether the regional allocation of tourism subsidies has been expended on the most adequate locations where regional development and tourism planning would objectively allocate them. Summing up, the subject matter of this paper is the survey of the settlement level relations among the supply and demand of tourism and the spatial-economic differences.

## 2. Literature review

Evaluating the spatial dynamics of tourism is a reasonably well focused direction of tourism research (Hall 2008, 2012; Connell 2009; Yaoqing 2011). The different approaches of these investigations on destination planning, economic and social impacts became fundamental for modern tourism research and for the creation of regional tourism policies both in general (Butler 1980; Font, Ahjem 1999) and as regards regional perspectives (Terluin 2003; Archer, Fletcher 1996).

We basically know those models that evaluate certain factors and impacts of tourism, such as those developed by Williams and Cartee (1991), Crompton and Shuster (2001), Crompton (2006) and Dwyer et al. (2004), which are concerned with the economic impacts of tourism or the economic evaluation and measurement possibilities of these impacts. Hall and Boyd (2005) evaluated the relationship between peripheries and tourism, but few researchers tried to analyse the factors spatially and the impacts of spatial dynamics of tourism. For example, Imran and Bhat (2013) published their findings on determining tourism potential in creating a destination based on balanced tourism development from a regional perspective (Kashmir Valley). A valuable contribution was carried out by the ESPON Monitoring Committee (2006), whose research team published important findings on the spatially relevant aspects of tourism. Aubert et al. (2010) used complex geographical methods in order to determine the tourism destinations of a region. The spatial-geographical perspectives of Varjú et al. (2014) were emphasized when the authors introduced methods with landscape evaluation and target group preference weighting.

One of the closest studies to the present article was published by Deskins and Seevers (2011): the authors investigated whether state expenditures were effective in terms of tourism promotion and general economic growth. These investigations were carried out in U.S. states and focused on regression models to identify the effect of tourism support; however, they did not deal with geographical issues.

Another aspect of related research is the monitoring and evaluation approach to regional support of the European Union. A relatively great number of researchers dealt with creating a methodology in order to generally or comprehensively evaluate cohesion policy. Bosch-Domènech and Escribano (1998) expanded professional knowledge with an evaluation index of the regional allocation of public funds. Bachtler and Wren (2006) and Busillo et al (2010) published the results of much broader research, such as the evaluation opportunities of the EU's cohesion policy and measuring the impact of European regional policy on economic growth. Rodríguez-Pose and Fratesi (2004), Becker et al. (2010) and Armstrong et al. (2012) also analysed regional aspects of the allocation of support and grant systems. Significant focus on investigating the tourism relations of EU funding was primarily carried out and proposed by the European Commission. The most relevant of these working papers is the ex post evaluation of Cohesion Policy programmes 2007–2013 (European Commission, 2014). In addition to such general and comprehensive studies, member states also regularly publish evaluation papers, usually after the completion of a particular planning period, but these approaches focus on economic aspects with no regard for complex spatial relations.

This paper extends these earlier works by applying spatial-geographical methods in the evaluation processes of the spatial dynamics of tourism in Hungary, South Transdanubia. As regards the expected outcomes and results, this work may assist a more effective decision-making process, at the same time reducing risks of the planning processes and provide a geographical approach for the monitoring indicators.

## 3. Research methods

The municipal-level regional investigation of the spatial distribution of tourism requires a complex methodology in analysing both tourism supply and tourism demand. In order to achieve this, the following methods were utilised:

A scientifically accurate, up-to-date tourism attraction survey and tourism product portfolio was carried out for the region. This first stage of the research was based on the Attraction Survey carried out by the Hungarian Tourism Ltd. in 1997. This survey covered all the settlements of Hungary, collecting data on three types of attractions: physical natural, cultural and special attractions. These were later evaluated on a uniform criteria scale, with values ranging from 1 to 9 for any attractions, in which 1 meant an attraction of local significance and 9 an attraction of international importance (Aubert et al. 2010).

The data of this attraction survey was updated and re-evaluated by the author during 2011–2013 where the settlements of the South Transdanubian NUTS II region were personally visited carrying out an updated attraction survey of 5,000 items (attractions) for the 656 settlements. In this process the methodology of the 1997 Attraction Survey and Aubert et al. (2010) was used (the evaluation method of the attractions from 1–9 is defined in detail in the Appendix).

The attractions of the settlements were identified, collected, grouped, and rated by the determining tourism products. It should be highlighted that in this research the author used the aggregated result whether an attraction (with functioning attraction zone) or attractions can be found or not at the settlement. In this database only attractions were collected with at least 4 value points in the system of the 1997 Attraction Survey and Aubert et al. (2010): that is, those that can attract (statistically demonstrable) tourists, not only visitors (Appendix).

For the general spatial-statistical analysis the main indicators of tourism (statistically measurable data on commercial and private accommodations and guest flow) were provided by the official database of the Central Statistical Office (CSO) of Hungary. Also included in the survey were the spatial investigations of the financial supports received in favour of tourism from 2004–2013. Such data was received from the database of the Hungarian National Development Agency (2014). Finally, the complex settlement development index of the CSO of Hungary (HCSO, 2013) was also applied. This index was elaborated by the CSO, covering the complete range of social-economic indicators of Hungarian settlements. After the elaboration and weighting of the data, the settlements were classified in a 0–100 scale. For the survey the author listed the data relevant for the 656 settlements of South Transdanubia.

The results were obtained and map visualisations were carried out with GIS methods using ARC/GIS 9.2. ARC/GIS Spatial Analyst. The numeric analysis was made by Microsoft Excel.

## 4. Results and discussion

### 4.1 Municipal-level relations among tourism attractions, support sources, and spatial-economic differences

When determining the presence of tourism generating attractions, altogether 207 settlements were categorised (with at least value number 4, see the Appendix), covering 31.55% of all the settlements in the region. Although the research also categorised the different tourism products and the absolute number of attractions, at this stage we only used information on whether or not tourism generating attraction or attractions were present at any settlement analysed.

After determining the spatial allocation of functioning tourism attractions, investigation of tourism demand indicators started. Based on the spatial presence of commercial and private accommodations in South Transdanubia, we can state that out of the 656 total settlements, 112 realised officially some level of accommodation turnover (Figure 1).

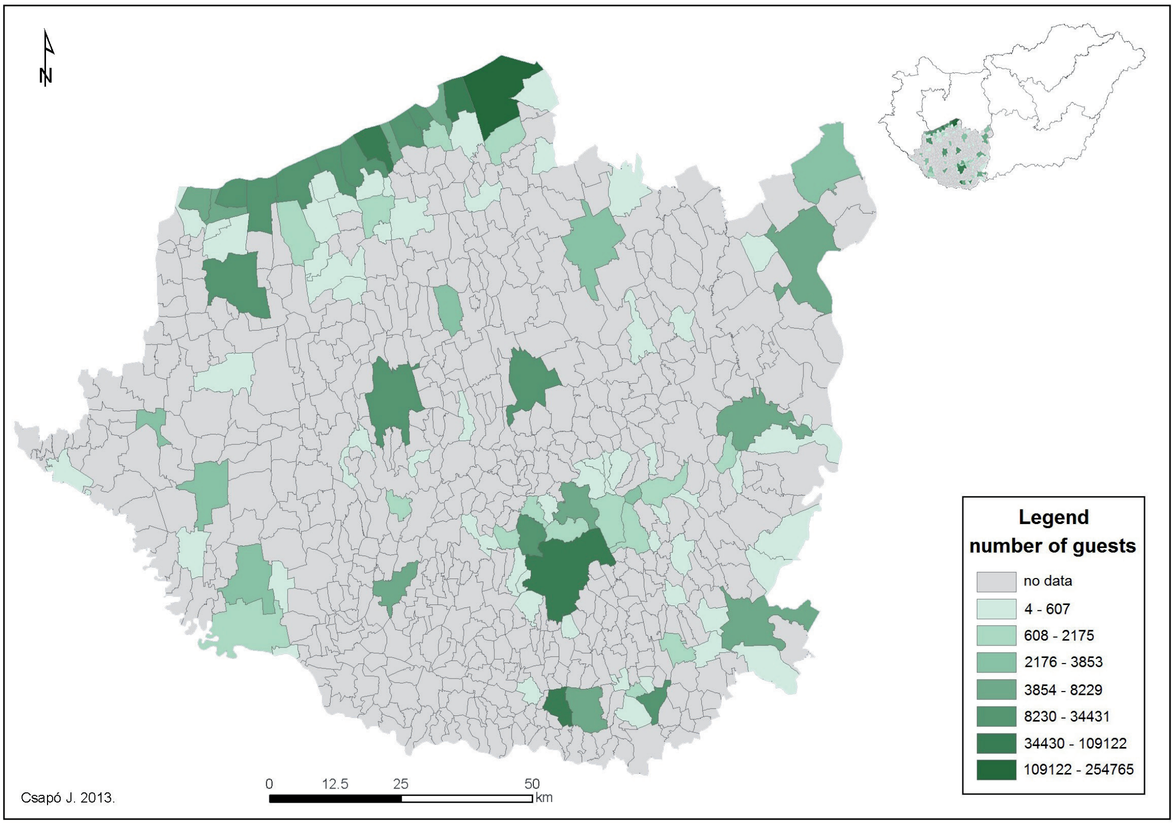


**Fig. 1** The spatial distribution of all the turnover of commercial and private accommodations in South Transdanubia (2013).
Source: Edited by the author, 2013.

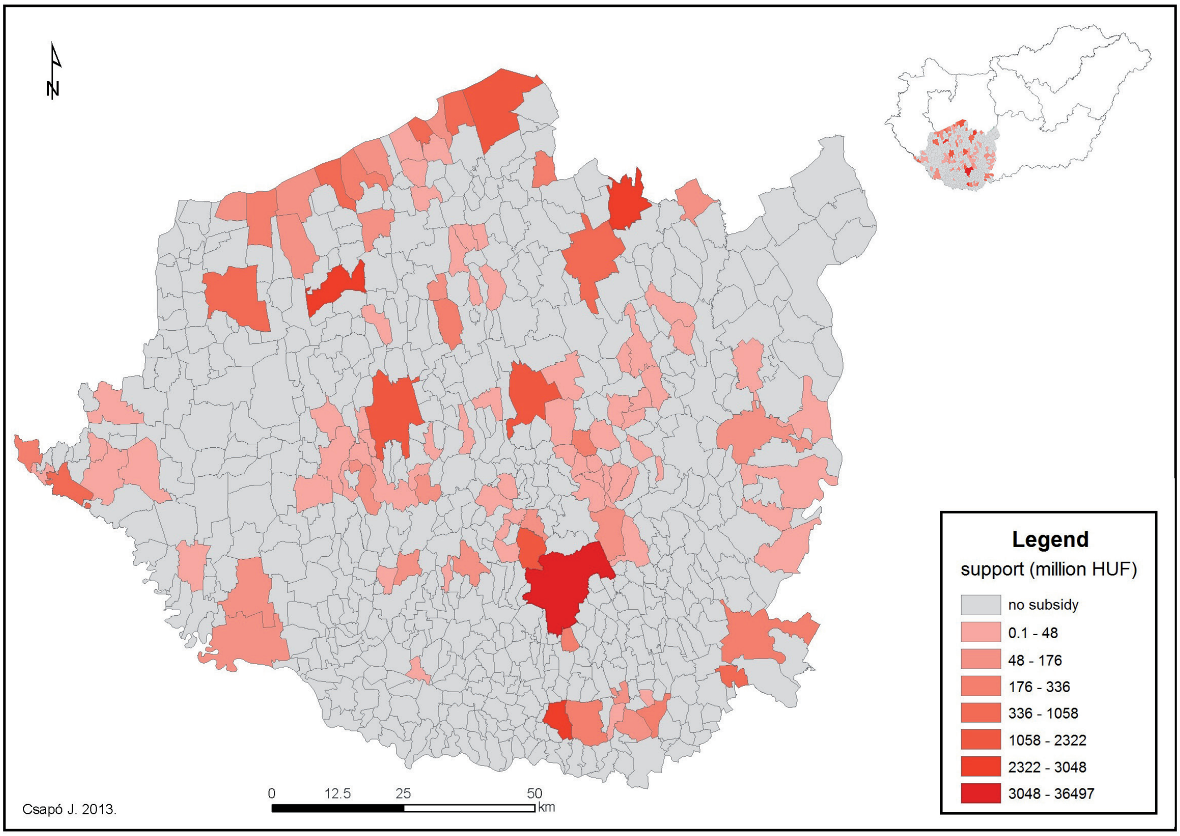


**Fig. 2** The spatial allocation and quantity of tourism support sources in South Transdanubia.
Source: Based on the database of the National Development Agency, 2013 edited by the author, 2013.

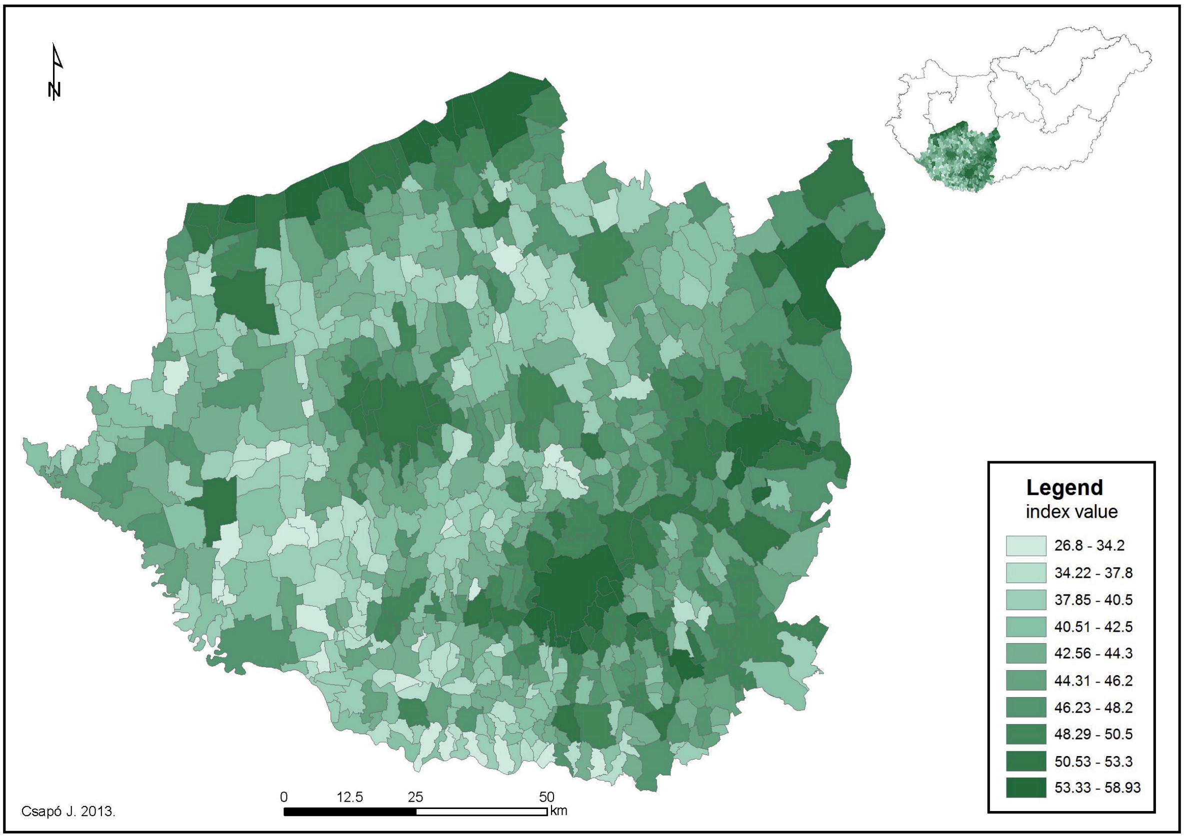


**Fig. 3** The settlement development index of the CSO and its spatial distribution in South Transdanubia.
Source: Based on CSO database, 2013 edited by the author, 2014.

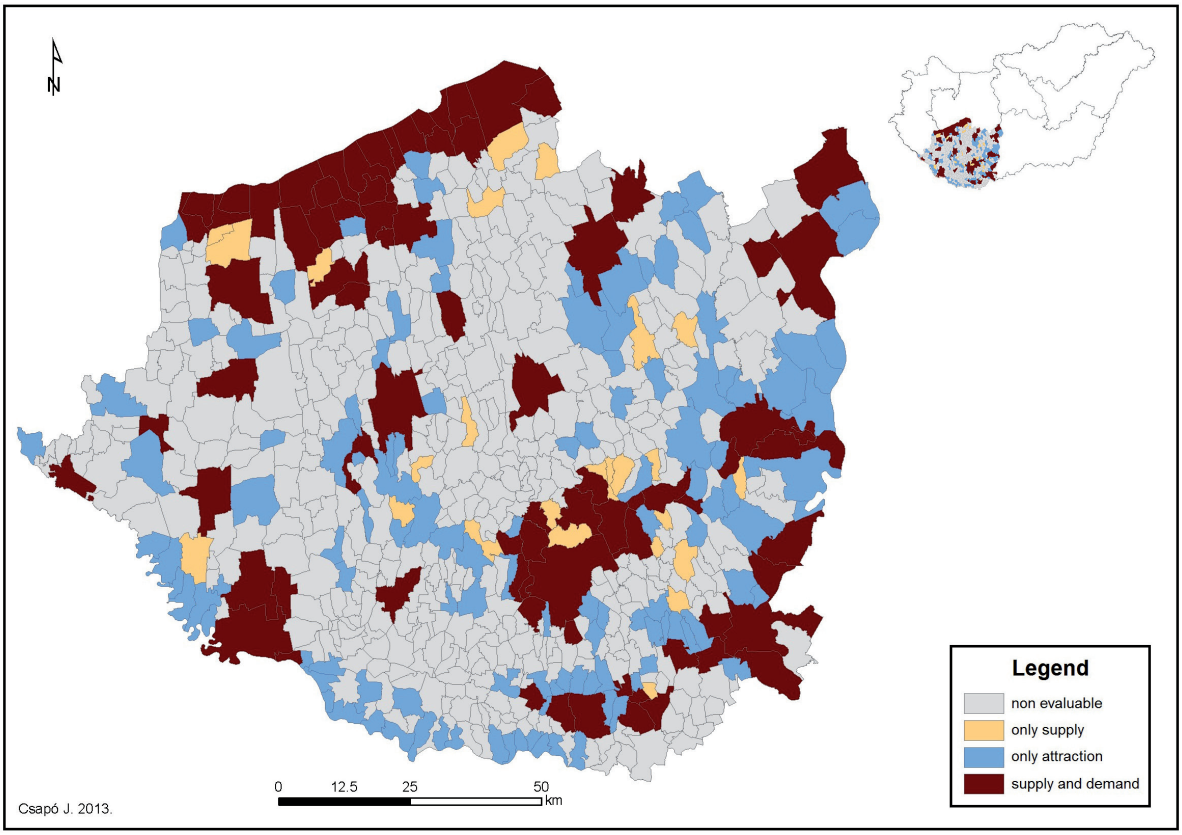


**Fig. 4** The relationship between tourism attractions and the tourism demand (accommodations) in South Transdanubia.
Source: Based on CSO database, 2013 edited by the author, 2013.

As the next step of the survey, the spatial allocation and the quantity of tourism support sources were identified. During the research, three EU planning periods were covered from 2004 (the joining of Hungary to the EU) to 2013 (end of the last EU planning period). The database was provided by the National Development Agency of Hungary (data downloaded in 2014). Out of these sources, all the projects directly connected to any form of tourism development were collected (accommodation development, tourism product development, tourism destination management development, cross-border programmes, infrastructure development, education programmes, fostering enterprises, and local product development) (Figure 2).

The last aspect of this part of the research was to spatially elaborate the settlement development index developed by the National Statistical Office of Hungary. As mentioned earlier this methodology is based on an evaluation and statistical weighting of complex social-economic aspects on a 0–100 scale. This research was carried out by the CSO in order to determine the preferential (underdeveloped) settlements – those micro regions where development sources should be allocated (105/2015. (IV. 23.) Governmental Regulation). In Figure 3, the deviation of the index is illustrated between the maximum and minimum values of the South Transdanubian region (Figure 3).

## 4.2 Comparative analyses after the elaboration of the collected databases

As the first step of the qualitative comparative analysis, the relationship between the spatial appearance of tourism attractions and the presence of the guest flow of the accommodations was examined. Despite the fact that initially some anomalies were expected in the region in this respect (where, for instance, a highly appealing attraction is allocated in a settlement with no accommodation capacity), the quantity where there was no such coexistence was surprising.

Figure 4 (the settlements indicated in black) shows the coexistence of tourism accommodation demand and the attractions, so in this advantageous situation a certain demand is realised based on the existing tourism attractions.

Altogether, 226 such settlements were identified with some level or form of attraction and/or tourism demand comprising 34.45% of all the settlements of the region. A total of 81 of these settlements demonstrate both accommodation demand and tourism attraction, representing 35.68% of the 226 settlements. If we would like to evaluate the supply and demand relations of the region, this data proves to be disappointing; however, we understand that in numerous cases an attraction can be found in the vicinity of the settlement where there is only

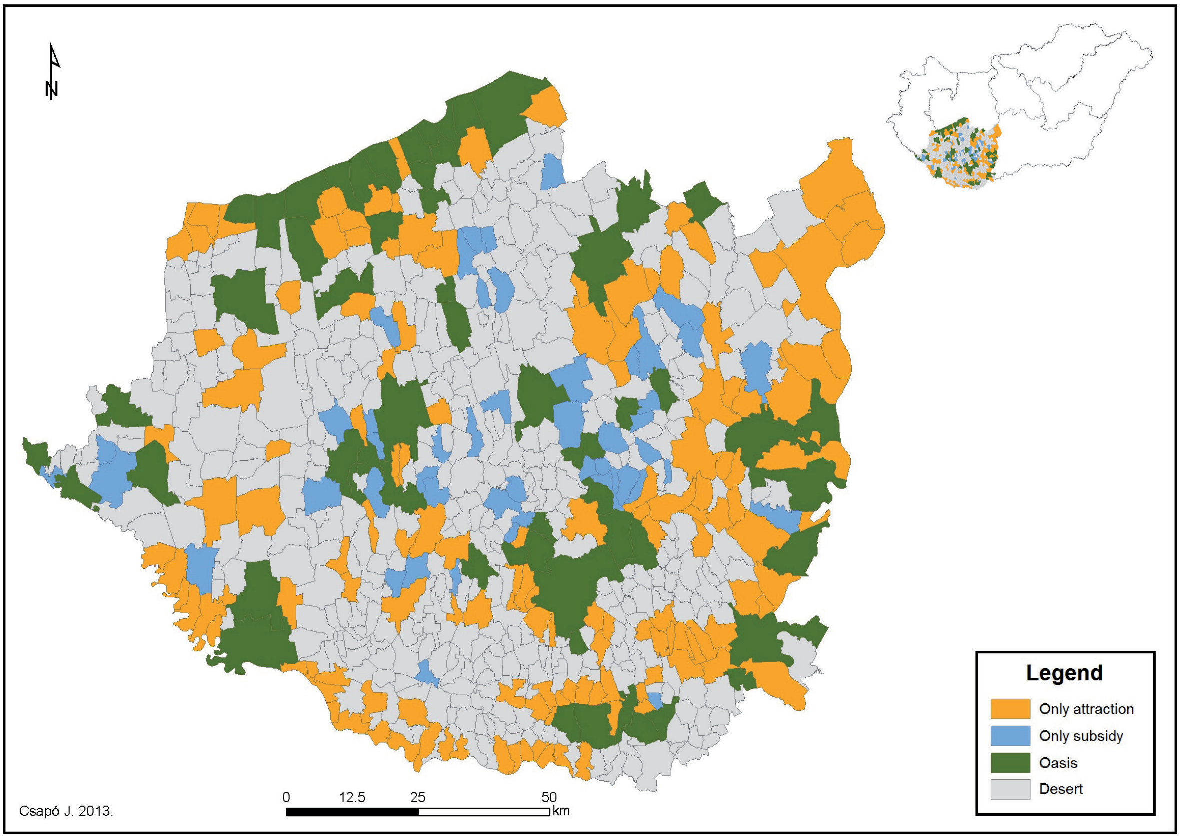


**Fig. 5** The relationship between tourism attractions and tourism supports in South Transdanubia.
Source: Based on National Development Agency database, 2013 edited by the author, 2013.

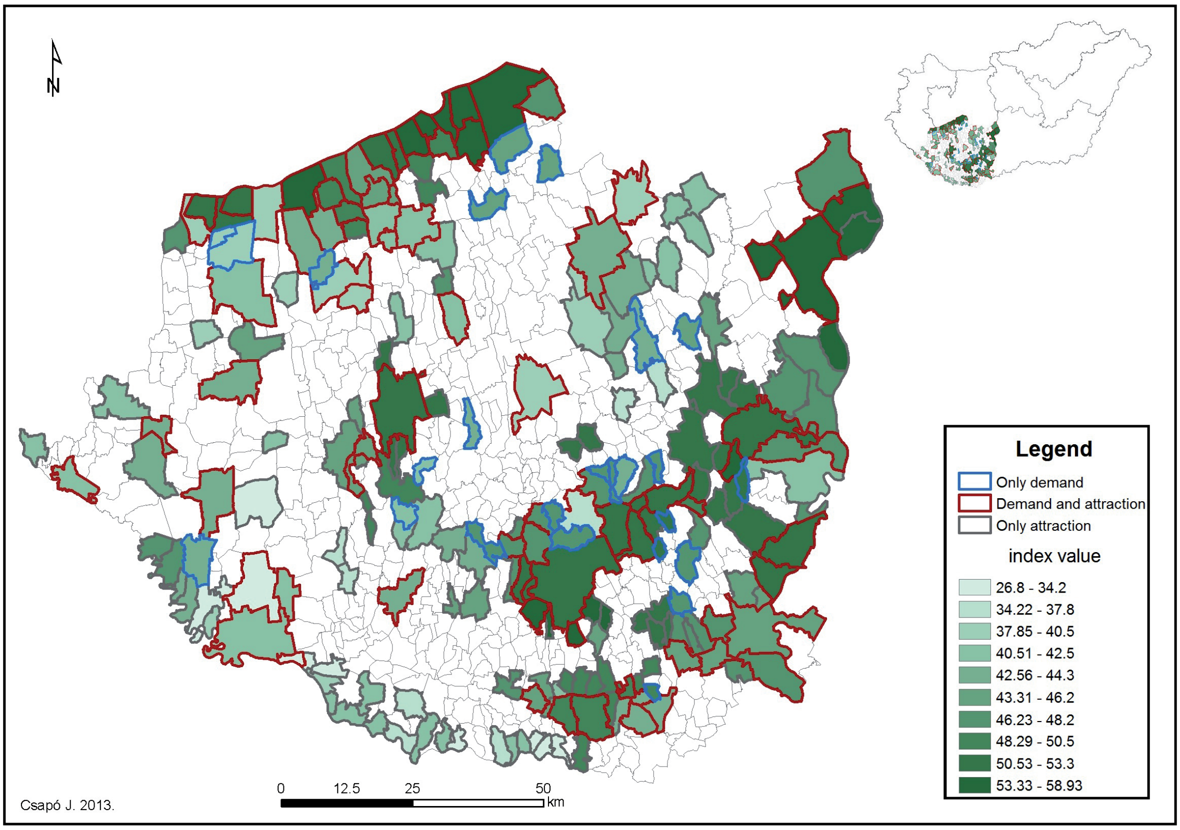


**Fig. 6** The relationship between the CSO settlement development index and the presence of tourism (attraction, demand) in South Transdanubia.
Source: Based on HCSO database, 2013 edited by the author, 2013.

accommodation, for instance. According to the survey, this figure grows only to 42–45%, if we join these neighbouring settlements.

In this respect we have to state that entire regions lack tourism complexity (along the Drava and Danube rivers, internal parts of Tolna county, and the South of Somogy county). The number of settlements with only accommodation demand is 25 (or 11.06% of the 226 settlements), whereas the number of settlements with only tourism attractions is 120 (53.09%). This data point clearly reflects that the presence of attractions of the region is inadequate to generate a certain kind of tourism demand (applying accommodations), which is also worrying, since only attractions that theoretically can generate functioning tourism flow were mentioned and used in this survey (above value point 4).

From this survey it seems that a complex and well-functioning tourism flow is realised only in settlements where both supply and generated demand are present, typically at waterside resorts (Lake Balaton), at health tourism centres (all the spas of the region), at cultural tourism, and at wine tourism centres. Only in the limited number of cases we can see active tourism generating supply and demand in the same settlement, especially in the case of hunting tourism.

The next phase of the research analysed the possible correspondence between the appearance of the tourism attractions and the spatial allocation of tourism support sources gained during the planning periods from 2004 to 2013. The basic question was whether it was evident that the registered tourism attraction(s) at a given settlement could generate functioning tourism flow where, besides the formation of demand, the need for tendering activity would appear as well, with tourism becoming a priority in the economic life of the settlement.

During the investigations it has been revealed that in the analysed region there are 405 settlements where there is neither tourism supply nor support. This group of settlements was entitled "desert" (Figure 5). Here one might expect that where there is no tourism attraction, one should detect no financial tourism support. However, further analysis highlighted numerous anomalies. For instance, there are 141 settlements where there is generated tourism supply from the point of view of attractions, but there is no detectable financial support. This would not be as worrying as the next result, according to which there are 49 settlements in South Transdanubia with (a certain amount of) financial support, but with no attractions whatsoever (Figure 5).

Of course, besides these raw numbers and figures, one should carry out an analysis with strong spatial-geographical perspective as well. Thus, the analysis involved the tourism structure of the neighbouring settlements (the presence of attractions, investments, and support), since the settlements are not necessarily allocated directly in the vicinity of a settlement with functioning tourism supply and demand. We also have to mention that investments belonging to this group primarily strengthened rural tourism, so they were only small/scale supports. Still, it is worth raising awareness of the fact that financial support was allocated for tourism development with no functioning tourism attraction in the locality.

The next group of settlements, called "oasis", was made up of 61 villages or towns where the tourism attractions and tourism supports were present as well (Figure 5). This group of settlements, the most viable in terms of tourism development and planning, where the presence of tourism provided adequate motivation for development activities, accounted for 9.3% of all the analysed settlements of the region.

It should be noted that in this research it was not the aim to find the exact reasons (political interest, corruption, or lack of professional knowledge) behind the outlined anomalies, since the author believes that it is extremely problematic to detect and prove objectively the mentioned presumptions.

The last segment of this research was a comparison of the spatial functioning of tourism and the settlement development level as determined by the CSO. Here the author was interested in whether the existing tourism activity of a settlement indicated automatically a more developed settlement level and whether a highly developed settlement possesses automatically a functioning and developed tourism as well.

For these investigations a map was created on the basis of the CSO database (Figure 6). On this map those settlements were indicated where there was tourism attraction and demand, only demand, or only tourism attractions. The figure clearly indicated that the settlements with tourism supply and demand did not necessarily belong to the most developed settlements. However, the majority of the most developed settlements possessed a real and functioning tourism. Nearly half of the settlements with tourism supply and demand at the same place belonged to the moderately or less developed group.

## 5. Conclusions

The most important aim of this research was to reveal possible anomalies of tourism development planning and practice from a geographical perspective in South Transdanubia, a Hungarian NUTS 2 region. The author believes that the presented research can provide useful results for such areas of interest as regional development and tourism, rural development and tourism and the spatial relations of the EU support sources. We received answers for the spatial relations concerning the presence or lack of tourism attractions, tourism supply, demand, spatial allocation of the EU financial sources and the development level of the region's settlements.

In the first phase of the research, an attraction survey was carried out in order to map the attraction structure and the spatial allocation of tourism supply. Results

**Tab. 1** Evaluation of Tourism Attractions by their Reach.

| Attraction value point | **Attraction category, reach** | **Complementary terms** |
|---|---|---|
| 1 | Local attraction 1: Can be developed to potential attraction | Local inhabitants know about the attraction and visit it, but without any tourism flow. If a tourist arrives there – and obtains knowledge about it – visits the place as a complementary program, but does not travel to the settlement only because of that particular attraction. |
| 2 | Local attraction 2: With a reach and visit of a micro region | The neighbouring inhabitants are aware of it and show it to their guests. It has a certain tourism flow as well but does not generate independent demand. |
| 3 | Regional attraction 1: The majority of visitors come from the given region; induces significant turnover | It is a known, visited, and recognized attraction in the region, but is not familiar outside the region; its external demand is negligible. |
| 4 | Regional attraction 2: The majority of the given attraction's visitors arrive from the same region but it also attracts visitors from settlements in the neighbouring region (tourists from remote regions or abroad are present but in small numbers) | It is well known in its region, the population of the region consider it as part of its image and visit it regularly. It is externally known as well outside the regional boundaries and thus receives external visitors. |
| 5 | National attraction 1: The visitors of the attraction come from the entire area of the country but they only mean a special guest flow segment; the attraction does not generate significant international visits | The attraction is completely accepted and accentuated in the region, generating demand for one guest segment from the complete country (e.g., a cross-country track) but does not motivate other segments. |
| 6 | National attraction 2: The visitors of the attraction come from the entire country in every segment; the attraction does not generate significant international visits | Generates visits in almost all visitor segments but is only known and received by the domestic culture (linguistic, historical peculiarities) and has no international attraction. |
| 7 | International attraction 1: A significant ratio of visitors come from abroad but it is basically attractive from one special segment (ratio of domestic guests is lower) | Its significant international guest flow has a special interest segment (e.g., hunting tourism). |
| 8 | International attraction 2: A significant proportion of visitors comes from abroad, representing a wide range of segments (ratio of domestic guests is lower) | It attracts a significant international guest flow, mostly from neighbouring countries and from traditional sending countries. Its demand is massive but does not generate new markets in its present state, although it has potential. |
| 9 | Global attraction: Its interpretation exceeds the previous category in that the attraction induces global tourism flow and visits to the area independent from geographical distance | In Hungary there are few of them such as Budapest and the Hungaroring Formula 1 race track. |

Source: Aubert A. et al 2010

showed that functioning tourism generating attractions can be found in 207 settlements (31.55% of the settlements in the region). Tourism demand was investigated by the presence of any commercial or private accommodations. Data showed that 112 settlements (17.07%) had statistically detectable amount of accommodation turnover.

In the second phase the relationship between the spatial appearance of the tourism attractions and the presence of the guest flow of the accommodations was analysed and it uncovered numerous anomalies. Out of the 226 settlements with any level or form of tourism attraction and/or tourism accommodation demand, we identified only 81 combined a tourist attraction with statistically demonstrated accommodation demand. So the majority of the settlements possess no adequately functioning tourism where supply and demand are present in a balanced manner and thus we can conclude that the existing attractions in general cannot generate tourism demand to the settlements.

The next steps included the data collection and visualisation of the spatial allocation of tourism support sources. Results proved that the majority of the region's settlements (405, 61.73%) had neither tourism supply nor support. Interestingly, there were 141 settlements with generated tourism supply but without any financial support for tourism. However, the more intriguing phenomenon was that there were 49 settlements with detected financial tourism support but without any tourism attractions. The number of settlements where tourism attractions and tourism supports were present at the same time was low, only 9.3% of the analysed settlements (61 altogether).

The last stage of analysis investigated the relationship between the spatial functioning of tourism and the settlement development level. The survey showed that settlements with tourism supply and demand are not necessarily the most developed ones, meaning that tourism cannot be the only way for economic prosperity. However, it was proved that the majority of the most developed settlements are characterised by well-functioning tourism supply and demand.

Summing up the findings, important lessons can be learnt from such demonstrated anomalies where tourism demand and supply can be found not necessarily together with the presence of tourism attractions or products or, where tourism support is also allocated at such settlements where there is no (real) tourism attraction or product.

The presented research can therefore provide an impetus for the research and practice of the complex relationships between regional development and tourism, rural development and tourism as well as for the monitoring of the application of EU financial support in favour of their most beneficial social-economic utilisation.

One of the important results of this research is that its methodology can be easily used in any other European Union member countries, both on regional and national levels. Since all the member states need to serve statistical data to Eurostat, these data are reliable and comparable. It is not only Hungary that produces anomalies in the practice and theory of tourism development, so it would be a relevant topic and area of research to make a comprehensive survey in the European Union as well. Another aspect and direction of this work is to use this method and approach in any other member countries of the European Union as part of the monitoring process of the financial resources since the more adequate and detailed the monitoring process is, the more we learn to create a better and more effective regional policy.

Turning back to the question of whether we can see a balanced or an unbalanced development of tourism in South Transdanubia, we can state that further efforts should be made by the decision makers in order to avoid the revealed anomalies and so we would be able to achieve a more professional and more focused regional development of tourism industry in South Transdanubia.

Further directions of this research may be the application of more in-depth quality studies to be able to demonstrate more particular and more detailed results and relevancies. One of these directions may be the investigation of both tourism demand and supply where not only the existence but the rate and measures of the indicators can be examined.

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# ANAEROBIC BIODEGRADATION OF DDT IN CONTAMINATED SOIL BY BIOSTIMULATION: LABORATORY AND PILOT-SCALE STUDIES

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**ABSTRACT**

Bioremediation of 1,1,1-trichloro-2,2-bis(4-chlorophenyl) ethane (DDT) by biostimulation of native microbial populations in soil was investigated in a lab-scale and pilot scale under anaerobic conditions. To evaluate the role of molasses (co-substrate) and potassium nitrate (electron acceptor) in the reductive dechlorination of DDT, experiments were conducted in a microcosm using five treatments: (T1) control, (T2) natural attenuation, (T3) molasses, (T4) molasses + potassium nitrate and (T5) potassium nitrate. Results showed that after 30 days of incubation, DDT concentration was reduced by 30.3% in the control, 32.85% for natural attenuation, 72.3% with addition of molasses, 92.5% for amendments with molasses + potassium nitrate, and 70.2% for biostimulation only with potassium nitrate. An upscaling of the microcosm to a larger fixed-bed reactor was conducted for treatment T4. After one month of incubation, DDT concentrations in the reactor decreased by 91.54% of the initial quantities. The DDT biodegradation rate fit a pseudo-first-order kinetic decay function and declined to 0.077 $d^{-1}$, with half-life of 8.9 days in the absence of oxygen. Predominant microbial strains were isolated and identified through biochemical and molecular tests before and after the bioremediation process. The microorganisms isolated were identified as Bacillus circulans and Bacillus megaterium before and after the treatment application, respectively. This study provides evidence that the combination of a donor electron substance (molasses) and acceptor electron ($KNO_3$) can enhance the DDT biodegradation rates under anaerobic conditions.

**Keywords:** biodegradation, DDT, molasses, potassium nitrate, anaerobic conditions.

Received 14 November 2016; Accepted 26 September 2017; Published online 10 October 2017

## 1. Introduction

DDT (1,1,1-trichloro-2,2-bis(4-chlorophenyl) ethane) has been widely used since the 1940s as an insecticide to control mosquito-borne malaria and typhus (Foght et al. 2001). Its use was banned in most countries by the early 1980s due to its deleterious impact on wildlife and human health via the food chain (Purnomo et al. 2011). Despite having been banned for over 40 years, DDT contamination is still widely prevalent in many sites around the world. In Colombia, it is estimated that there is 5000 $m^3$ of DDT-contaminated soils (Arbeli 2009).

DDT has a high persistence in soil (half-life between 10–50 years) due to its molecular structure, which contains chlorinated aliphatic and aromatic structures that impart great chemical stability. Additionally low aqueous solubility and adsorption of DDT onto soil organic matter decreases its degradation by microorganisms (Robertson and Alexander 1998). The lipophilic properties of DDT allow it to accumulate in the food chain and in the fatty tissues of organisms, affecting the central neural system, liver and kidneys, and causing reproductive disorders. The International Agency for Research on Cancer (IARC) has determined that DDT is possibly carcinogenic to humans (US-DHS 2002).

Considering their potential negative effects, it is very important to develop an efficient remediation technology for DDT contaminated soils. Bioremediation has been the cost-effective method of treating various pesticides (aldrin, heptachlor, endosulphan, including DDT) (Rani and Dhania 2014).

Reductive dechlorination is a fundamental pathway for DDT degradation in the absence of free oxygen because the five electrophilic chlorine atoms on the DDT molecule make aerobic oxidative degradation difficult. Reductive dechlorination is a form of anaerobic respiration in which the chlorinated compound is used as the terminal electron acceptor by dechlorinating microorganisms (Holliger and Schumacher 1994).

It has been demonstrated that bioremediation of DDT is a co-metabolic process requiring an additional organic substrate (electron donor, organic carbon source) to provide energy (electrons) to indigenous microorganisms (Baczyński 2013). In recent years, evidence has shown that organic acids, alcohols, glucose, and complex organic materials acting as electron donor substances can be used in contaminated sites for the reductive dechlorination of chlorinated pollutants (Chen et al. 2013; Ortiz et al. 2013).

The rationale behind the use of soluble or biodegradable co-substrates in the degradation of persistent molecules is that these co-substrates can promote microbial growth and induce the activation of enzymes that participate in pollutant degradation (Purnomo et al. 2010).

https://doi.org/10.14712/23361980.2017.16
Prada Vásquez, M. A. – Cardona-Gallo, S. A. – Loaiza-Usuga, J. C. (2017): Anaerobic biodegradation of DDT in contaminated soil by biostimulation: laboratory and pilot-scale studies
AUC Geographica, 52, No. 2, pp. 199–207


**Fig. 1** Study site.

Further, addition of easily biodegradable organic matter stimulates anaerobic, low-redox potential conditions necessary for intensive metabolism of DDT (You et al. 1996).

Studies on the degradation of DDT using liquid-phase tests inoculated with sediment containing DDT-degrading microflora, found that DDT removal was fastest when yeast extract was used as a substrate, while glucose was the slowest.

This research evaluates anaerobic biodegradation of DDT in laboratory and pilot scale experiments using a co-substrate and an electron acceptor to stimulate soil microbial populations. Based on the degradation rate, molasses was selected as a possible supplemental carbon source, along with nitrate (in the form $KNO_3$) as the nitrogen source. In the first phase, lab-scale tests were established in microcosms to investigate the individual and interactive effects of the co-substrate (molasses) and electron acceptor (potassium nitrate) on biodegradation of DDT. The second-phase developed and evaluated the biodegradation kinetics of DDT in the absence of oxygen at a larger scale by applying an optimal strategy in a fixed bed reactor. The effect of relevant variables, such as concentrations of DDT and physicochemical characteristics, was investigated for both experimental phases.

## 2. Materials and methods

### 2.1 Soil collection

Soil used for both experimental phases was collected at an agricultural area located in Codazzi (Cesar, Colombia) with a previous history of DDT contamination (Fig. 1). This region has soil types ranging from incipient development soils, such as Inceptisols, to soils with a high degree of weathering, such as Oxisols (Instituto Geográfico Agustín Codazzi 1986). Soils were dry and well drained, indicating that these soils may likely have high rates of mineralization of organic matter. The predominant soil textures are sandy loam and loam.

Samples were taken at three different points and top layer (0–40 cm) of the soils was removed. To ensure homogeneity of pollutants in samples, the soil was crushed and then passed through a 2-mm sieve.

Soil properties were measured using standard methods for soil analysis. Soil texture was characterized using the Bouyoucos method (Bouyoucos 1962). Soil water content was determined by placing samples in an oven at 105 °C for 24 h (Jackson 1964). Organic matter (Walkley and Black 1934), pH, electrical conductivity (Jackson 1964), ammonia, nitrate (Nessler 1999) and phosphorus content (Bray and Kurtz 1945) were assessed previously.

### 2.2 Microcosm setups

Lab-scale microcosms were carried out in a 3.8-L rectangular plastic tray. Five treatments were conducted in this phase: (T1) control, (T2) natural attenuation, (T3) molasses, (T4) molasses-$KNO_3$ and (T5) $KNO_3$. Each microcosm was filled with 1 kg of contaminated soil; three replicates were used. To maintain anaerobic conditions, soil samples were maintained at field capacity, which corresponded to 30% humidity to generate a low oxygen transfer into and through the soil. Microcosms were moved to closed room without direct sunlight; they were also sealed with a plastic liner to prevent air exchange. For abiotic controls (T1), soil was sterilized by autoclaving at 121 °C for 15 minutes at 1.05 kg/cm$^2$ pressure and 2M HCl was added as a microbial inhibitor.

The amount of nutrients required for the (T3), (T4) and (T5) treatments was calculated using stoichiometric relationships established by the McCarthy method of the DDT concentration of the soil, and the amount of nitrogen and phosphorus required to produce biomass. The C:N:P ratio was 100:5:1 (mass/mass/mass), which is comparable to the values reported previously in bioremediation studies (Atagana et al. 2003). In treatments T4 and T5, 1.5 g of $KNO_3$ was added as a nitrogen source and electron acceptor. Molasses was applied in the treatments T3 and T4 in single-doses at the start of the experiment (In et al. 2008). These experiments were conducted for 30 days and the concentrations of DDT were measured (USEPA SW-846 2007; USEPA SW-846 1996a; USEPA SW-846 1996b) at the beginning and end of each treatment.

### 2.3 Pilot-scale test

A pilot-scale ex situ bioremediation experiment was performed in a fixed bed reactor. In this experiment, the microcosm was upscaled by 3-fold. Likewise, the amount of nutrients (C:N:P ratio of 100:5:1) and the field capacity moisture content of the soil was maintained. The reactor was constructed with 5 mm thick acrylic material. The dimensions were: 77 cm × 50 cm × 27 cm. The amount of contaminated soil added to the reactor was 60 kg.

DDT concentrations were measured every 4 days during a 1-month period and the degradation kinetics were assessed. At the end of the treatment, predominant colonies were isolated and identified during the biostimulation strategy through biochemical and molecular tests.

**Tab. 1** Physical and chemical properties of contaminated soil samples from Codazzi (Cesar, Colombia).

| Parameters | Value |
|---|---|
| Soil texture | Loam |
| Sand (%) | 38 |
| Silt (%) | 36 |
| Clay (%) | 26 |
| pH | 6.6 |
| Organic matter (%) | 1.9 |
| Water content (%) | 1.4 |
| Electrical conductivity (dSm$^{-1}$) | 0.12 |
| N-$NH_4$ (mg kg$^{-1}$) | 14 |
| N-$NO_3$ (mg kg$^{-1}$) | 4 |
| Total phosphorus (mg kg$^{-1}$) | 120 |
| Total DDT (mg kg$^{-1}$) | 72.35 |

### 2.4 Analytical methods

#### *2.4.1 Chemical and physical parameters*

Redox potential, pH and electric conductivity values were measured with a portable multimeter HQ40d (Hach, Loveland, CO, USA). Ten grams of soil (dry weight) was mixed with 25 ml of distilled water to a concentration of 1:2.5. The mixture was with a vibration stirrers Vortex (FALC ®) for 90 seconds and the electrode was inserted

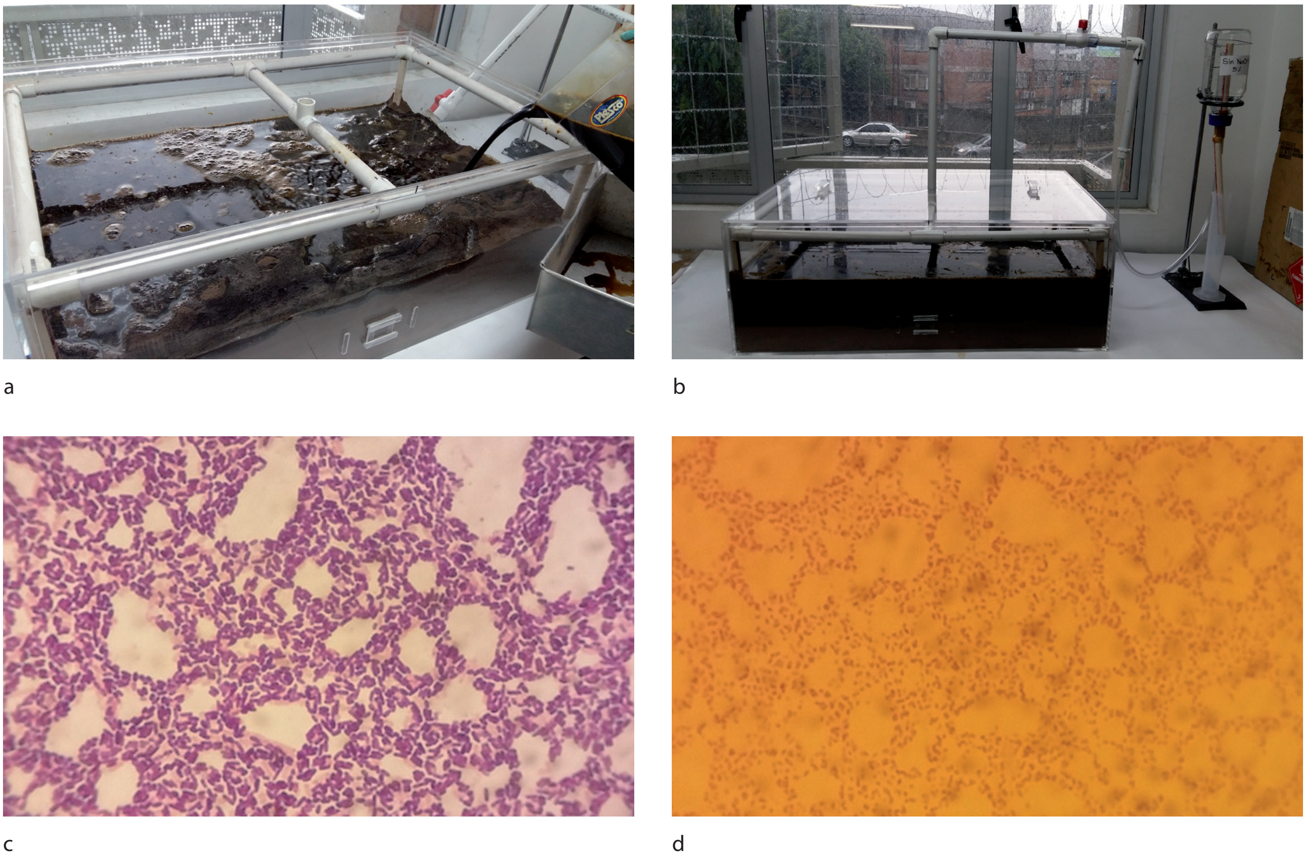


**Fig. 2** Lab scale microcosm: a) treatment of molasses-$KNO_3$, b) microcosms experiment, c) bacteria's in contaminated soil (100×), d) bacteria's in decontaminated soil (100×).

in the solution. Soil temperature was measured using a hand-held digital thermometer.

#### *2.4.2 DDT extraction from soil samples*

Soil samples were extracted by ultrasonic extraction described in US EPA method 3550C with some modifications (USEPA SW-846 2007). Each sample (1 g dry weight) was spiked with 100 µL of the surrogate and mixed with anhydrous Na2SO4. A 50:50 (V/V) mixture of hexane and acetone (10 mL) was added, and the mixture was dispersed for 6 min using an ultrasonic cleaner (Model 2510-DTH; Branson, CT, USA). Finally, the extract was filtered through 3-cm thick glass wool. This procedure was repeated three times. Extracts were decreased to 2 mL by way of rotary evaporation under vacuum at 55 °C. The percentage of recovery from this method was 101(±2)% for DDT.

Cleanup was performed using US EPA method 3630 C (USEPA SW-846 1996a). Deactivated silica gel (1.5 g) was transferred into a 1 cm ID column and a 1-cm layer of anhydrous $Na_2SO_4$ was used to cap the silica gel. The column was prewashed with 20 mL of hexane before use. The concentrated extract was transferred into the column, and then eluted with 8 mL of hexane (fraction I), 6 mL of hexane (fraction II), and 1.5 mL of dichloromethane (fraction III) at a rate of 5 mL/min.

#### *2.4.3 GC analyses of DDT*

GC/MS analysis was performed in an Agilent gas chromatograph (Agilent Technologies, CA, USA) equipped with an electron micro-capture detector and a capillary. A 1-µL sample was injected and separated on a capillary column (ZB35HT Inferno Zebron 30-m length × 0.25-mm ID × 0.25-µm film thickness, Phenomenex, CA, USA). The GC conditions were: split injection (injector temperature 280 °C, split 1/8 for samples and 1/20 for standard samples); oven temperature programmed from 80 °C (held for 3 min) to 160 °C, then raised by 2.5 °C/min to 180 °C and held for 7 min (USEPA SW-846 1996b). The carrier gas was Helium. Internal standards were spiked in each sample prior to quantification.

#### *2.4.4 Heterotrophic plate count*

Bacterial populations were counted by the pour plate method in LB (Luria Bertani) medium. A 1 g sample was diluted in 9 ml of 0.9% sterile saline solution (10-1). A 1 ml sample was then taken and transferred to a tube containing 9 ml of sterile saline (10-2). Serial dilutions of soil were prepared until a dilution of 10-4was reached (Carter and Gregorich 2008). Plates were incubated in anaerobic conditions at 35 °C for 3 days. Soil microbial counts were tested for both phases every four days during 1 month.

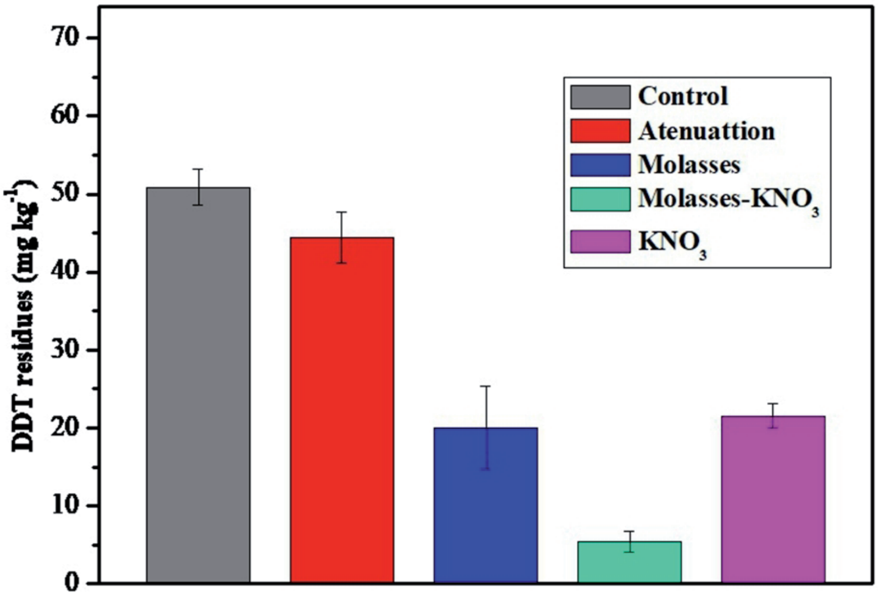


**Fig. 3** Final concentration of DDT for each microcosm treatment after 1 month of incubation. Error bars represent standard deviation of results.

## 2.5 Microorganism isolation in the reactor

Soil bacterial strains before and after the treatment applied at the pilot scale were isolated from colonies formed on the plates after incubation at 35 °C for 3 days (Carter and Gregorich 2008). The isolated colonies formed on the LB agar plates were identified using biochemical tests such as gram stain and catalase. Catalase activity was determined by adding a fragment of a purified colony to hydrogen peroxide and observing the presence (catalase (+)) or absence of bubbles (catalase (–)) (Maehly 1954). Gram staining test was determined by Carlone's Method (Carlone 1982) and was observed under a light microscope (Nikon E200, Japan ) with a magnification of 100×.

## 2.6 Identification of cultivable bacteria

The isolates corresponding for B1 (contaminated soil bacteria) and B2 (clean soil bacteria) were purified by repetitive sub-culturing on nutritive agar. Genomic DNA was extracted using the GeneJet Genomic DNA Purification Thermo Scientific kit following the protocol for Gram negative bacteria (Sambrook and Russell 2001).

The 16S rRNA gene was amplified by PCR using 27F (5′-AGAGTTTGATCCTGGCTCAG-3′ and 1492R (5′-TACGGYTACCTTGTTACGACTT-3′) primers. Each PCR amplification cycle consisted of 30 sec at 94 °C, 30 sec at 55 °C and 1 min at 72 °C. PCR amplification was confirmed by agarose gel electrophoresis. The amplified PCR product was purified using the PureLink PCR Purification Kit (Invitrogen Life Technologies, Burlington, Ontario, Canada). The 16S rDNA sequencing from the isolates was analyzed by the BLASTN tool with GenBank databases on NCBI (www.ncbi.nlm.nih.gov).

## 3. Results and discussion

### 3.1 Soil properties

After 1 month of incubation, physical and chemical properties of the soil varied. Phosphorus content in the soil increased to 127 mg kg$^{-1}$; content of nitrogen N-$NH_4$ and N-$NO_3$ also increased to values 6 and 23 mg kg$^{-1}$, respectively, due to the addition of molasses and potassium nitrate solution (nitrogenous compounds). Studies have shown that the addition of N and P to soil contaminated with organic compounds stimulates biodegradation and increases the diversity of microbial species (Bray and Kurtz 1945). The soil texture had fixed percentages of sand, silt and clay: 40, 36 and 24% respectively. Previous research showed that the degradation of DDT is more favorable at a pH of approximately 7 rather than at basic pH values close to 9 (Rittmann and McCarty 2001). At the end of treatment T4, the pH increased to 7.3; due to flooding conditions pH tends to increase as a result of consumption of hydrogen cations (H+) in the reduction reactions.

### 3.2 Microcosm experiments

Changes in the concentration of DDT for each treatment are presented in Fig. 3. The control exhibited a decrease in DDT concentration of 30.3%, and attenuation natural treatment (control) resulted in a decrease of 32.85% after four weeks. Loss of DDT in the control

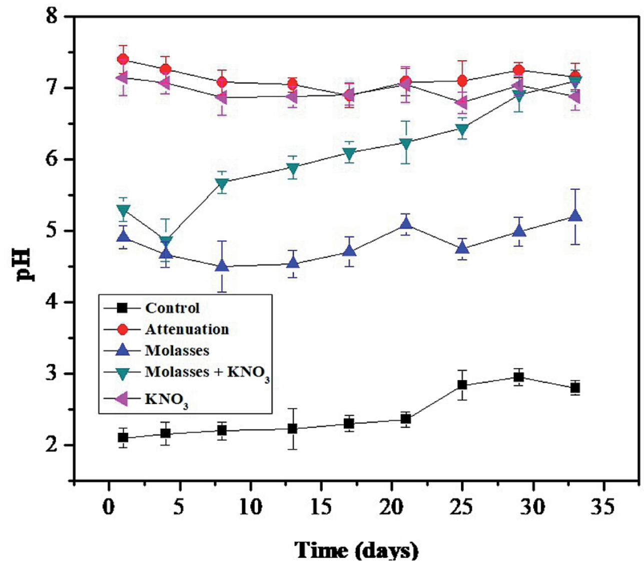


**Fig. 4** pH-dependent variation for each treatment. Error bars represent standard deviation of results.

treatment may be attributed to abiotic factors such as chemical transformations by adding HCl solution. Likewise, there is a possibility that some communities of microorganisms may tolerate extreme environments, as in this case where the soil presented low pH (Quatrini and Johnson 2016).

The nutrient additions affected the removal rate of pesticides when compared with the control and attenuation treatment. The results indicated that the application of either molasses or $KNO_3$ could accelerate DDT dechlorination significantly.

The DDT concentration was reduced by 92.5% with the application of molasses to the soil + $KNO_3$; by 72.3% with the molasses treatment, and by 70.2% with the $KNO_3$ treatment. The addition of molasses + $KNO_3$ showed the greatest effect in accelerating DDT dechlorination. This was primarily because the combination electron donor/acceptor produces a synergistic effect; molasses has a complex composition (sugars, proteins, minerals, among others) with a high microbial load and, combined with a terminal electron acceptor with a high reductive potential ($NO^{3-}$), it causes acceleration of contaminant metabolism and high rates of degradation, as obtained in treatment (T4). Several studies suggested that the application of molasses as an organic carbon substrate to create an anaerobic reducing environment through the use of microbes to facilitate dechlorination of contaminants. In general terms, molasses provides more organic carbon to microbes in the soil so that they increase in number and metabolize the contaminants (Brent 2012). Results confirmed the importance of addition an easy biodegradable co-substrate for the effective anaerobic biodegradation of DDT. This was particularly clear for samples with no electron donor added, where the decomposition of DDT was low (T5). The application of both an electron donor substance and an electron acceptor might be a feasible strategy to accelerate the reductive dechlorination of DDT. Therefore, results verify previous studies where it was found that reductive dechlorination of DDT under anaerobic conditions is much faster than the dehydrochlorination under aerobic conditions (Atlas and Bartha 1993).

### 3.5 Statistical analysis

An analysis of variance (ANOVA) was performed to compare whether applied bioremediation treatments differ significantly in DDT degradation ($p < 0.05$). The high value of F (62.06) indicates that individual and combined application of nutrients affect the rate of removal of DDT in different bioremediation protocols, showing that there is significant difference between the means of the five treatments. The homogeneity of variances was demonstrated using Brown and Forsythe test. The p-value (0.25) was > 0.05, indicating equal variances in the treatments applied.

### 3.4 Eh and pH values of the reaction systems

The pH variations are showed in figure 4 for each microcosm. The pH is an important physical factor that influences the biodegradation of organochlorine compounds, as it may affect the microbial activity and bioavailability of carbon and energy sources (Dibble 1979). In the control treatment, pH varied in the range between 2-2.5 due to the addition of HCl solution as a microbial inhibitor. This condition is toxic to microorganisms and affects the degradation of organochlorine compounds (Matzner and Prenzel 1992).

For treatment T3, soil pH decreased to values close to 5 caused by the application of a molasses solution with pH in the range 5.5–6. Treatment T2 maintained the pH value of 7.1 and its behavior was similar throughout the study because it nutrients were not added. The treatment with the addition of $KNO_3$ showed a pH variation ranging between 7–7.5 because potassium nitrate in solution results in essentially a neutral effect on the soil. The pH behavior for treatment T4 increased from 5.5 to 7.2, possibly due to adding nutrients to the soil. The results showed that the pH favored a higher rate of degradation of DDT. The greatest loss of DDT was in treatment T4 where in the second week, pH was in the range of 6.5–7, compared to the pH in the molasses assays (T3) was above 5–5.5 during the bioremediation.

Values of Eh for treatments at each sampling time are presented in Table 2. From the beginning to the 21th of incubation, Eh values of the reaction systems were significantly different for treatments T1, T2 and T5 with positive values recorded until the third week. The more rapid decrease in redox potential occurred in treatment T4 due to the greater amount of bioavailable carbon, which likely resulted in greater microbial oxygen consumption that drove the potential redox down. These results showed that the application of molasses or $KNO_3$ could enhance the reducibility of the reaction system, and the effect of

**Tab. 2** Time course of redox potential values for each treatment.

| Treatments | Redox potential (mV) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Time (days) | | | | | | | | |
| | 1 | 4 | 8 | 13 | 17 | 21 | 25 | 29 | 33 |
| 1. Control | 150.7 | 140.6 | 120 | 82.3 | 70.6 | 30.5 | 20.3 | 8.34 | −1.5 |
| 2. Natural attenuation | 122 | 95.9 | 80.3 | 50.7 | 45.3 | 20 | −1.5 | −5.1 | −18.3 |
| 3. Molasses | −10.1 | −13.6 | −63.1 | −125.8 | −140 | −160.2 | −176 | −180 | −185 |
| 4. Molasses + $KNO_3$ | −89.4 | −90.2 | −105 | −113.9 | −119 | −124 | −163 | −231 | −265 |
| 5. $KNO_3$ | 73.5 | 65.8 | 56.5 | 34.3 | 1.5 | −35.5 | −50.3 | −72.2 | −80.8 |

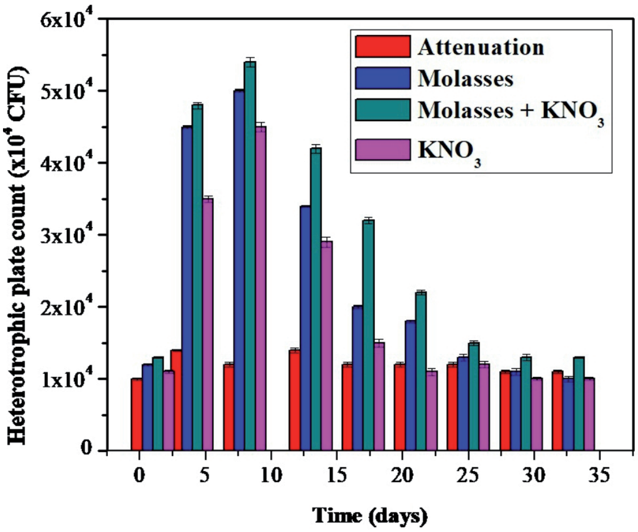


**Fig. 5** Heterotrophic plate count in the microcosm treatment for each sampling time. Error bars represent standard deviation of results.

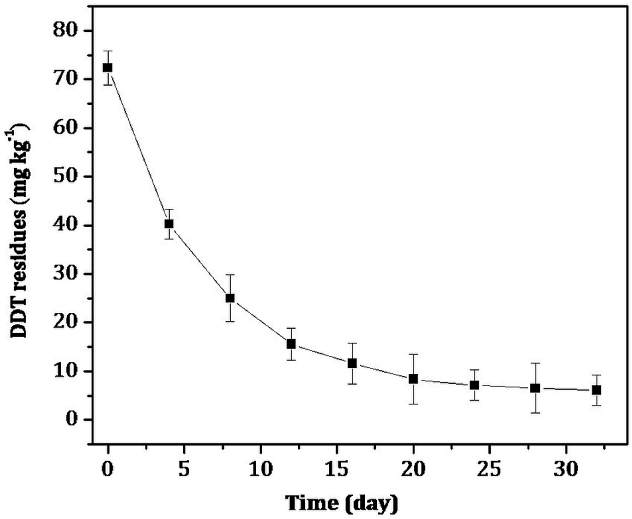


**Fig. 6** Evolution of DDT concentration in the reactor during treatment (T4). Error bars represent standard deviation of results.

molasses was greater than that of $KNO_3$. Furthermore, the application of molasses + $KNO_3$ had the greatest effect in enhancing the reducibility of the reaction system, indicated a synergistic reaction between molasses and $KNO_3$.

### 3.6 Heterotrophic plate count in microcosm

Bacterial growth during the biodegradation assays are presented in figure 5. The heterotrophic count in the lab-scale experiment showed an increase of CFU (colony forming units) in the first week of incubation and, for the treatments T3, T4 and T5, lasted until the second week. During the third week, heterotrophic bacteria decreased considerably and possibly caused by the lack of nutrients in the soil. In the attenuation treatment, CFUs showed a stable behavior during treatment because no carbon and energy source was added. Treatment T4 had a greater density of bacteria compared with the treatments T3 and T5, with a maximum value of 5.4 × 104 CFU/g soil.

Mal'tseva and Golovleva (1985) mentioned that the activity of the dehydrogenase during the intake of carbon amendments with high content of energy can generate cofactors that can be involved in the dechlorination of the DNA. The results show that DDT degradation was directly proportional to growth of the cultures and the indigenous microbial population in the soil was able to utilize molasses + $KNO_3$ as a carbon and energy source, due to the lower concentration of DDT in treatment T4, which had greater CFUs.

### 3.7 Pilot-scale test

Concepts related to the greatest loss of DDT observed in the microcosm studies were extended to a larger scale. The molasses-$KNO_3$ treatment was selected and performed in a fixed bed reactor. Changes of residues of DDT in the reactor are presented in figure 6. The results showed DDT concentration was reduced by 91.54% and declined rapidly in the first 9 days and then slowly after 24 days.

In this study, the degradation of DDT in soil fit a pseudo-first order kinetic relation, which agreed with many prior investigations. Previous research found that the anaerobic dechlorination of DDT in the sediment by adding short chain organic carbon sources was pseudo-first-order kinetics (Zhao et al. 2002).

The kinetics equation was $\ln C_t = -kt + \ln C_0$, where t is the degradation time, $C_0$ is the initial concentration of

DDT, $C_t$ is the residue of DDT at the t day, k is the degradation rate constant, and the half-life of DDT is 0.693/k. The value obtained was a constant degradation rate, indicating that DDT declines to 0.0784 per day parts of pollutant with a half-life of 8.9 days. This shows that the application molasses-$KNO_3$ under anaerobic conditions, can significantly reduce the DDT half-life.

It has been shown that the combination of a co-substrate/electron acceptor applied to DDT-contaminated soil can accelerate the dechlorination of organochlorine in anaerobic conditions and achieve half-lives between 8 and 12 days (Liu et al. 2015).

### 3.8 Isolation and identification of culturable bacteria

Two representative colonies were isolated, one belonging to DDT contaminated soil and a second colony after being applied biostimulation treatment in the reactor. The catalase test is one of the most useful diagnostic tests for the recognition of bacteria due to its simplicity. In performing the catalase test, bacteria B1 bubble was observed and in contrast, bacteria B2 produced no bubble, indicating that the isolated bacterium is catalase negative and could not mediate the decomposition of $H_2O_2$ to produce $O_2$. For test Gram stain was obtained bacilli Gram positive in both bacteria. Previous research demonstrated that Gram-negative and Gram-positive bacteria, such as Alcaligeneseutrophus, Hydrogenomonas sp. and Pseudomonas putida, which have the metabolic capability to attack DDT (Sonkong et al. 2008).

It was possible to extract the DNA and successfully amplify the gene 16S of the samples under study. According to the Blastn tool, sequences homologous to samples B1 (contaminated soil bacteria) and B2 (soil bacteria after treatment) were detected with the genus Bacillus, which were used as references for subsequent phylogenetic analysis for samples, as shown in Table 3.

**Tab. 3** Identification of bacterial isolates before and after the treatment.

| Isolate | Degree of similarity | Description |
|---|---|---|
| *Bacillus circulans* | 99% | Before treatment |
| *Bacillus megaterium* | 100% | After treatment $T_4$ |

According to the distance matrix, that could be identified for bacteria B1, Bacillus circulans and for bacteria B2, to the reference sequence of Bacillus megaterium, indicating Bacillus gender was able to resist to the contaminant present in the soil. Researchers have demonstrated the capabilities of anaerobic bacteria to degrade DDT through reductive dechlorination mechanisms, such as: Bacillus sp. Pseudomonas aeruginosa, Escherichia coli. Proteus vulgaris (Katayama 1993).

## 4. Conclusions

The biostimulation treatment with molasses-$KNO_3$ represented the highest percentage of DDT removal (92.5%). By contrast, removal of 72.3% and 70.2% was obtained in the molasses (T3) and $KNO_3$ treatments (T5), respectively. This shows that the combination of a donor electron substance and acceptor electron produces a great increase in the presence of heterotrophic bacteria in the soil, and consequently an increase the DDT dechlorination. Although the contaminant is used as the sole source of carbon and energy in most cases, the microorganisms present in the soil are unable to metabolize a compound as sole carbon source. Therefore, a kinetic study evaluated in the fixed bed reactor demonstrated the efficiency of treatments in anaerobic conditions to bioremediate DDT contaminated soil. It was concluded, based on the constant degradation rate that 0.0784 parts of pollutant disappears per day, that it is possible to carry out bioremediation of DDT through biostimulation at a larger scale.

Bacterial plate count increased, corresponding to DDT removal. As bacterial count increased, the DDT concentration was reduced. A 16S rDNA analysis allowed us to identify predominant bacteria, such as Bacillus circulans before treatment and Bacillus megateriun during bioremediation T4, which indicates the great capacity of the Bacillus gender to resist contaminant in the soil.

## Acknowledgements

The authors would like to thank the National University of Colombia, Medellin, especially the Faculty of Mines, for the support through the infrastructure of Bioremediation and Technological Development laboratory. The authors would also like to thank the Information System Research Hermes Medellin for the financing of this investigation (No. 200000013887) and to the administrative department of Science, Technology and Innovation-COLCIENCIAS for the scholarship Young Researchers (No. 645). We also like to give special thanks to Prof. Roy Sidle for greatly improved the quality of this paper.

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# THE REGION AS A CONCEPT: TRADITIONAL AND CONSTRUCTIVIST VIEW

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**ABSTRACT**

The main goal of this article is to assess and compare the various understandings of the concept of the region. The aim is to characterize the concept of a region as well as how its meaning has changed through geographical history, to mention the most important personalities and how they understood the concept of region. The article presents two different ways of looking at a region: 1) the region in the sense of traditional regional geography; 2) the region in the new regional geography (region understood as a social construct). The article then compares the two approaches and outlines both their advantages and their disadvantages. The first section presents a brief overview of how the understanding of the concept of region developed. The following part focuses on development of the concept of region as a social construct, especially in the context of the development of new regional geography, cultural turn and new regionalism. Finally, the article emphasizes the essential complementarity of the two approaches and briefly proposes a more complex scheme of analysis of a region.

**Keywords:** region; traditional regional geography; new regional geography; region as a social construct

Received 20 March 2017; Accepted 25 July 2017; Published online 31 October 2017

## 1. Introduction

"*Geography changes as society changes.*" (Livingstone 1992: 347)

According to its advocates, regional geography is the core and heart of geography, the highest art of a geographer and the reason for its existence, and the advocates call for "back to the basics" (Whittlesey 1954; Hart 1982; Watson 1983; Lewis 1985). According to spatial scientists, regional geography is not exact, it does not search for laws and regularities, and its lack of a theoretical and methodological framework excludes it from the portfolio of exact sciences (Fred K. Schaeffer [1953] and other advocates of geography as a spatial science). Due to its philosophic-paradigmatic background there are also different views of the conceptual shape of regional geography, its idiographic or idiographic-nomothetic character, its focus on explanation or understanding and so on.

Many authors have participated in the discussion about the character of regional geography (Hartshorne 1939; Whittlesey 1954; Hart 1982; Johnston, Hauer, Hoekveld 1990; Entrikin, Brunn 1989; Nir 1990; Wood 1999; Claval 2007). On one hand there are the ever-strengthening positions of the advocates of "traditional regional geography" who emphasize a "return to the basics", "heart of geography", "nature of geography" (Hartshorne 1939), and a return to Hartshorne (Entrikin, Brunn 1989). Many of them stress the uniqueness of locations: "Hartshorne is correct about the uniqueness of locations" (Bunge 1979: 173). Their arguments are also supported by an emphasis on the importance of local scale in postmodern geography (Duncan 1996). On the other hand, there is a new (reconstituted, transformed, reconstructed) regional geography (Gilbert 1988) which started the exactization process of regional geography. This has meant there is a visible shift of approach in regional geography, mostly a more significant orientation towards processes and contexts (Tomaney 2009).

The difference between traditional regional geography and new regional geography (social-constructivist approaches in regional geography) has kept increasing gradually (Paasi 2009). The division of regional geography into two different approaches brought about several discrepancies. As a consequence, it influenced regional geographical practice and the way a region was understood, i.e.: what is a region (a complex unit or a social construct); what isn't a region (the social-constructivist new regional geography does not take nature sufficiently into account); how to investigate a region (social-constructivist approaches emphasize that contexts and underlying processes are important, whereas traditional regional geography is rather a descriptive science). Traditional regional geography uses traditional methods (statistical analysis, fieldwork, regionalization etc.), whereas new regional geography uses qualitative and contextual methods. Traditional regional geography attempts to "see the region objectively", whereas new approaches see the region more subjectively. This has led to our decision to focus on the meaning of the concept of region, and to focus on how this meaning developed over time. We also wanted to provide a comparison of basic approaches.

https://doi.org/10.14712/23361980.2017.17
Kasala, K. – Šifta, M. (2017): The region as a concept: traditional and constructivist view
AUC Geographica, 52, No. 2, pp. 208–218

In this article, we focus on the changes in understanding the concept of region as follows: its complexity; its synthetic character; its unity; the role of man, nature and society in the formation of region; the interconnections of its individual parts; uniqueness; dynamic vs. static character; region as a result of development vs. region as a process. The difference between the traditional concept of a region and a region as a social construct (as understood in new regional geography) is as follows:

| Traditional concept of a region | A region as a social construct |
|---|---|
| Complex | Predominantly social |
| Static | Dynamic |
| As a consequence of development | As a consequence of process |
| Understanding | Explanation and understanding |
| Actors: man/society and nature | Actors: society |
| Geographical spheres: physical-geographical; economic; social; cultural; political | Geographical spheres: predominantly social and political |
| Unique, as a consequence of unique combination of phenomena | Unique, as a consequence of factors and processes |

As well as the term region, we also use the terms landscape (landscape, according to Carl Ortwin Sauer can similarly be understood as a region) and place ("Even for many new regional geographers, the meanings of region and place are more or less similar or overlapping"; Paasi 2009: 224).

This article was written by two authors. One is a regional geographer and presents his view of a region from the point of view of traditional regional geography. The other is a social geographer and represents the approach of social constructivism in new regional geography.

The resulting article focuses on how the understanding of the concept of a region developed throughout the history of geography. The main goal is to assess the various understandings of the concept of the region and to present the most appropriate conceptual framework for a region and understanding it. The authors attempt to find answers to the (following) research questions: How has the meaning (understanding) of the concept of region developed over time? How was the concept of region perceived by significant geographers? What were the weaknesses and strengths of the main approaches? What are the main contributions of the main approaches? How can the positive aspects (those bringing some benefits) of both approaches be used when characterizing a region? In the conclusion, we offer a proposal for an analysis (and of synthesis) of a region, using the methodological contributions of both traditional and social-constructivist understandings of a region. The article takes the form of a discussion between the supporters of the traditional meaning vs. supporters of the region as a social construct (Hart 1982; Hartshorne 1939; Johnston, Hauer, Hoekveld 1990; Murphy 1991; Paasi 1986; Sauer 1925; Semian 2016; Whittlesey 1954 etc.). This provides an analysis of the concept of a region in individual approaches, as well as an analysis of the concept of the region by different geographers. The comparison of different approaches (traditional vs. new regional geography) is based on an analysis of the strengths (primarily) and weaknesses. The strengths and weaknesses of these approaches (to the region) relate to the theoretical-methodological area (complex vs partial understanding of a region; static vs dynamic region; description vs contextual and processual understanding) and to applications (used in particular in regional development).

## 2. The concept of a region in traditional regional geography

Throughout the history of geography, the region was, and is, its most important topic, its main concept, and its main object of study. However, the concept of the region was understood differently throughout the history: a region was understood as a pure intellectual construction (Hartshorne 1939); as a concept or method (Whittlesey 1954); as a system (Nir 1990); as a total and complex unit (Paul Vidal de la Blache); or it was understood in the sense that a region is no more than a sum of its components (Hartshorne 1939), etc. During the 20th century, geography gradually split into two disciplines: human and physical (e.g. Hartshorne 1939). This was due to the following: 1) the importance of nature in the process of formation and development of the region kept decreasing; and 2) differences between the methodologies of natural and social sciences. As a consequence a region is understood as a social construct.

### 2.1 Origins of modern geography

Carl Ritter is the father of modern regional geography. He is the originator of new scientific geography, which is based on an organic unity between man and nature (Martin 2005: 125). "Ritter's … regional geography is conceived as *unity in diversity*; not an inventory, but an attempt to understand the *interconnections* and *interrelations* that make the area a mutual (*zusammenhängig*) association" (Nir 1990: 34). For Ritter, the earth and its inhabitants are in a close relation; the human and physical worlds are inseparable (Cresswell 2013: 40). In 1859, Darwin published his work *On the Origin of Species.* The subsequent approaches – social Darwinism and environmental determinism – explain regional differences as a result of the geographical environment. Such an approach had a decisive influence on geography at the turn of the 19th and 20th centuries (e.g. the determinist approaches of Friedrich Ratzel and other German authors, Ellen Semple, Ellsworth Huntington were prevailing).

## 2.2 Paradigm of regional geography

Starting from Vidalian geography we can notice a shift in the understanding of nature: man as an actor is being emphasized, and nature is perceived as a "product of the culture". Paul Vidal de la Blache is known as a representative of possibilism. As opposed to determinism, possibilism understands nature to be the possibility for regional differentiation. Vidalian geography and the whole of French regional geography were holistic and complex (*Géographie Universelle* as well as excellent local studies and regional monographs). Vidalian region is holistic and descriptive unit, with strong personality (Archer 1993: 499). Regional differences and *pays*, however, occurred mainly due to *genre de vie*. Man and human group can never escape the restrictions of the *milieu*, the natural surroundings upon which they depend (Mercier 2009: 148). It is necessary to add that *milieu* is not only the natural environment; Vidal makes a distinction between *milieu externe* (physical, not only natural world) and *milieu interne* (values, habits, customs).

Carl Ortwin Sauer, an influential American geographer, laid stress on culture in the landscape genesis, and he is thus a follower of the possibilist Vidal de la Blache. Carl Ortwin Sauer, however, includes nature in his view of landscape (region): "geography is based on the reality of the union of physical and natural elements of the landscape" (Sauer 1925: 325). He emphasized the division of forms into natural and cultural. The first part of his formal morphology includes both the reconstruction and the understanding of the natural landscape (ibid, from p. 333). It consists of geognostic and climatic factors, which are expressed in part through vegetation. Natural factors transform the natural landscape over time into forms (climate, land, sea and coast, vegetation), while creating a natural landscape. The second part of the morphologic analysis includes an analysis of the cultural landscape. Carl Ortwin Sauer argued that culture is the main agent in shaping the cultural landscape: culture is the agent, the natural area is the medium, and the cultural landscape is the result (Sauer 1925: 321 and figure, p. 343).

Both Alfred Hettner and Richard Hartshorne influenced the character of geography from the 1930s. William M. Davis described the landscape as a result of processes (such as erosion cycle etc.). His approach significantly influenced Hartshorne (Harvey 2009: 22), who wrote *The Nature of Geography* (Hartshorne 1939). The Hettnerian-Hartshornian chorology studied areal differentiation, and explained it by causal connections between phenomena. Hartshorne's chorology understands the region as a unique area and as a mental construct. In his diagram (Hartshorne 1939: 147, fig. 1). Richard Hartshorne placed an emphasis on regional geography, which in the physical-geographical and human-geographical point of view has a strong character of unity; physical geography is an essential part of geography (Butzer 1989). For Hartshorne, the region is the central organizing concept in geography (Smith 1989: 103). Regions are unique because they are unique combinations of phenomena. Hartshorne's approach is not problem-oriented; he wrote: "the interest of the geographer is not in the phenomena themselves, their origins and processes, but in the relations which they have to other geographic features (i.e. features significant in areal differentiation)" (Hartshorne 1939: 425–426).

## 2.3 Regional concept from the 1950s

*American geography: inventory and prospect* gives a deep insight into the perspectives of American geography. The main area of interest in geography covers areal differentiation; geography focuses on interregional similarities and differences, interconnections and movements and on the order found in space (Whittlesey 1954: 21). The region in Whittlesey's sense is a kind of a formal region. The region is a tool used by the regional method. Regions can be single, multiple or total. Complex regions are called total regions, *compages*: "Such a region is an association of inter-related natural and societal features chosen from a still more complex totality because they are believed to be relevant to geographic study." (Whittlesey 1954: 35–36). Geography as a spatial science continues to understand a region in such a formalized way (Whittlesey 1954). This approach was dominant in 1960s and is typical for emphasizing the formal side of a region – spatial pattern, interactions, regularities etc. Spatial science is based on the philosophy of neopositivism and places an emphasis on formulating regularities. As spatial science does not deal with unique regions and their specifities, in this article we provide an analysis only of the traditional region and the region as a social construct.

The development of geography was further influenced by its division into physical and human geography and by its further fragmentation. The ongoing process of the loss of unity was associated with developments in geography (environmental determinism → possibilism → probabilism; from 1980s postmodern and post-structuralist geographies). The emerging new regional geography and cultural turn in the 1980s changed the perception of the region into a region as a social construct. New regional geography turned regional geographers into systematic geographers (Wei 2006: 1397). The understanding of a region as a social construct (in Marxist approaches, a region is produced) is obvious and some authors characterize it as "social (cultural) determinism" (Graham 1999). Due to shift to social constructivism, several articles about the social construction of nature (Demeritt 2002; Evans 2008) and the social construction of scale (Marston 2000) were published. However, Gerard A. Hoekveld identified a new conceptual framework for regional geography, including 8 key concepts, of which only the seventh is nature, with a note: "In regional geography nowadays [nature] is still conceived in a more limited way." (Hoekveld 1990: 27)

And finally, the “more traditional” Israeli regional geographer Dov Nir wrote: “Regional geography deals with the *challenges posed* to a certain *society* at a certain *place* on the globe and with the *responses made by that society*. Its focus is the study of differentiation between societies …” (Nir 1990: 2). A divided geography, however, is “weaker”, its competitiveness and reputation fades (e.g. Matthews, Herbert 2004; Castree, Rogers, Sherman 2005).

## 3. The region as a social construct

### 3.1 From traditional to new regional geography

Regional geography primarily studies the relationship between humans and the environment they inhabit. “Traditional” regional geography encompasses distinct notions of that relationship, i.e. what is the character of the relationship between man and his environment (deterministic – seen from one direction [Ratzel, Semple] or from the opposite one [Durkheim], and possibilistic [Vidal de la Blache]). Regional geography distinguishes geography from the other “big” fields of science because it is interested “in everything”, although within a specific region, or, more precisely, because it studies and explains the differentiation between territories (regions). From the point of view of practical applicability, it abounds with great potential (regionalization, regional development).

Regions are not a purely geographical domain but are also used in many other fields – either as a method (a methodological approach to regionalization, e.g. comparing various regions in geopolitics), or as a tool/purpose (a pragmatic approach to regionalization – creating regions in order to establish, for example, electoral districts). Regionalization as a method has in fact “endured” even the harsh criticism of regional geography by so-called ‘spatial science’ in the period following the Second World War.

During the next paradigmatic turn and in the face of criticism from spatial science (which is unable to explain the differentiation of regional development, the way a particular regional organization was established, and the like) the dualistic concept gained strength in geography, which was by then splitting into human geography and physical geography. Regional geography, however, has the advantage of being able to work with knowledge from both these geographical disciplines which sometimes are separated in an overly artificial, dichotomous manner. That is where we see a great “strength” of regional geography.

From the 1960s, roughly, and then during the 1970s and 1980s – after positivistic spatial science encountered sharp criticism for its detachment from the reality of social and political affairs, the “dehumanization” of human geography – human-geographical paradigms have been fragmented into many various directions responding to the diverse problems faced by society: radical geography, humanistic geography, feminist geography, etc.

Regional geography was not the only field to have undergone this change in thought, focused on the influence of culture and society, as it also occurred in other branches of social and human sciences and which is generally referred to as the “social” or “cultural turn” (Barnett 1998, 2009). Another response of regional geography to the cultural turn is, besides the aforementioned multi-paradigmality, its multi-disciplinarity, i.e. adopting and applying methods and knowledge from other branches of social sciences and humanities (e.g. sociology, economy, psychology, historiography and many others).

In relation to regional geography (which has often been regarded as “dead”, namely by the adherents of spatial science; Gregory 1978), humanistic geography in particular is understood as a “return” toward the idiographic approaches of traditional schools of regional geography. It is not only about a simple return toward an idiographic conception of space; even though humanistic geography is once more concerned with the uniqueness of specific places or regions but primarily from the perspective of the essence of such uniquenesses, from the perspective of subjective meanings that a person (both the one in the studied environment and the one studying a given environment) attributes to a particular place/region, influencing the given place/region by her/his perception – here we see one of the roots of the so-called new regional geography. In today’s post-structuralist new regional geography, a region is perceived as a social construct continually endowed with subjective meaning and – just as in the case of an individual – characterized by a multi-layered identity (region as home, region as a political entity, region as an administrative unit, etc.).

### 3.2 The region as a social construct

Region specificity and incommutability had already been emphasised by Richard Hartshorne who claimed that a region was an arbitrarily delimitable territory, i.e. a sovereignly subjective matter. Even despite the prevailing systematization characterizing his approach (wherein chorology [regional geography] should involve “knowing everything” about a given territory [based, among others, on traditional German regional geography coined by Alfred Hettner]), his book titled *The Nature of Geography: A Critical Survey of Current Thought in the Light of the Past* (1939) can be understood, owing to the idea of the region as a social construct, as a “bridge” between traditional approaches to regional geography and the new regional geography. The concept of a region as a social construct later became the key concept within the new regional geography (Thrift 1983; Paasi 1986; Gilbert 1988; Murphy 1991; Schmitt-Egner 2002; Claval 2007).

Obviously, the concept of region as a social construct involves an enormous influence of culture and identity, or, more precisely, that of the cultural, historical and geographical context which plays a cardinal role in the formation of regions (other crucial concepts/key terms of both the new regional geography and the new cultural geography).

Traditional regional geography understood regions as a consequence of the interactions between society and its environment. From the point of view of the new regional geography, research into the interactions between man and nature, or rather, between society and environment, is being replaced with a study of the interrelationship between individual and society. The new regional geography no longer asks merely about "what", "where" and "when" but is interested primarily in the formation process of the region, in the way regions come to existence, for what reason and for what purpose they arise.

Various forms of the concept of a region can be found (not only) in geographical research. All the approaches mentioned above, regions created for the purpose of determining statistical or administrative units, "natural" regions as results of synthetizing analyses generated by traditional regional geographers are always, in a sense, a man-made construct. The region defined in this way is articulated from above by researchers, politicians and other actors; it is a secondary outcome of that particular activity in the course of which the region was established. This is the essential distinction from understanding a region as a social construct within the realm of the new regional geography. Here, regions are not approached as objects of study but rather as subjective constructs, a socio-spatial process. Regions arise from regional, social interactions that take place among individuals, groups and institutions in regional areas. Allen, Massey, Cochrane (1998: 50) suggest that a region is "the product of the networks, interactions, juxtapositions and articulations of the myriad of connections through which all social phenomena are lived out". Regions arise from interactions occurring at different hierarchical and scale levels of the society, i.e. through the actions among individuals, groups, institutions both within and outside a given region (Paasi 1986). As part of region formation, these relationships (all of them) are seen as reciprocal; constituting a condition for these interactions while being their result. It is not of substance whether or not a given individual considers a region to hold an important place in his/her everyday life, yet it is always produced and reproduced via ordinary activities. Kaj Zimmerbauer states that "at the core of social constructionism is the idea of region as a socially produced entity in which the regional consciousness of its inhabitants creates the whole idea" (Zimmerbauer 2011: 255). Individuals, groups and institutions active outside the region are of equal importance in the region-building process, regardless of whether or not they have the power to influence that process, and whether or not they do so deliberately (Paasi 2010).

Leaving aside all actors, their networks and mutual interactions, region formation is closely linked to the physical environment wherein a region is being constructed. A particular landscape and a specific natural environment markedly predetermines and affects both the material and the symbolic aspects of the region forming process, both its material form and its image (Šifta, Chromý 2014; Šifta, Chromý 2017). Many new regional geographers no longer pay much attention to the importance of the physical environment for regional formation. We do not suggest any return to Vidalian possibilism but '*pays*' and '*genre de vie*' cannot be entirely separated from the '*milieu*' (the physical environment) wherein they get their shape and which they obviously influence and transform (Claval 2007; Paasi 2010).

This understanding of the concept of the region as a socio-spatial process has not, however, been unanimous. In the past three decades during which the region as social construct was establishing itself within the new regional geography (Thrift 1983; Pred 1984; Paasi 1986; Gilbert 1988; Murphy 1991), the understanding of this and the approach to it naturally differed in terms of both space and time. Following this initial stage of theoretical and conceptual development of the social constructivist approach toward the region, a wave of (neo-)regionalism could be observed in the 1990s.

*Regions as a result of (neo-)regionalistic tendencies*

In Europe, (neo-)regionalism manifested itself (in connection to the building of a 'Europe of the regions' within the EU) through an approach to regions from a political and economic perspective (Hettne 2005). We can distinguish two basic types of regionalism: one bottom-up and one top-down. The first one developed mainly owing to voluntary initiatives of citizens living in each particular region or those of local subjects (e.g. microregions, transborder Euroregions and consensual associations of municipalities, etc.). In the second type of regionalism, the development of regions is initiated (taking the example of Europe) by the EU's central institutions with the aim of enhancing regional competiveness and reducing socioeconomic gaps between the developed and the less developed regions (Bristow 2010). Thus new regionalists, by supporting not only socioeconomic, but also sociocultural development of regions (the forming of regional identity including its impact on regional development), respond to the deepening processes of globalization and unification (Chromý 2009; Paasi 2012). They emphasize and take as a basis regional diversity as well as the specific material and cultural values of the given region (Keating 1998; Chromý 2009; Paasi 2012; Jones, Paasi 2013).

Similar manifestations of (neo-)regionalism were also observed in the United States (e.g. Wheeler 2002) and in those Eastern European countries that are not (or were not) EU members (e.g. McMaster 2006).

*The region as a brand*

The economic or marketing concept of regions represents another approach to regions as social constructs, which was well-marked especially in the first decade of the new millennium. Place marketing and place branding researchers point to the fact that regions are treated as commodities in order to make profit (either by attracting investors, encouraging new inhabitants to move in, or by increasing the turnout of tourism). However, the majority of regions "operate" with place branding and place marketing strictly at the level of "selling" a region as merchandise, using its brands with the aim of commodifying and commercializing it without taking into consideration that the two concepts must be seen as a long-term strategic, synthetic and integral, complex process. This process, which makes part of an overall strategy of the given region for preserving and enhancing its competitive ability, is supposed to satisfy all target groups (Anholt 2003; Hospers 2011; Zimmerbauer 2011; Pike 2009, 2011).

*Overlapping regions*

Another possible generalizing stream of working with the region as a social construct is constituted by "regional conflict" research projects, which we expect to grow in number in the near future. As is evident from the above, there are increasingly more regions of diverse character (administrative, economic and cultural; numerous tourist regions are emerging, NUTS system regions, transborder regions, all of them of various scale levels, etc.). Many of these more or less spatially delimited units overlap. Along with the changing context, many of them see their meaning change over time. Thus, conflicts of interest between different actors in regional initiatives become more frequent and regional identity becomes internally more fragmented. In addition, outward regional identity becomes ambiguous (Kašková, Chromý 2014).

## 4. Comparison of approaches: traditional and/or reconstructed region

### 4.1 The view presented by new regional geography

Owing to the revival of interest in regions within regional geography and beyond, research is becoming increasingly idiographic. When studying specific regions, new regional geographers, however, strive to reveal details on the functioning of regions, trying to make sense of the mechanisms of their formation, transformation and vanishing. Their objective is to interpret this idiographic knowledge, as it seems at first sight, by nomothetic means. The results of such efforts include, for example, Anssi Paasi's theory of institutionalization (Paasi 1986) as well as plentiful attempts to put this into practice (testing the region institutionalization process on specific regions). It is thus a combination of idiographic and nomothetic approaches.

We can, however, ask whether the existence of regional geography is legitimate and necessary. The pieces of knowledge that we learn about a region (as the main research topic) can be simply extracted from all the other systematic subdisciplines of geography, or from other scientific fields as a whole. For example, Gordon MacLeod and Martin Jones (2001) claim that priority is no longer given to only one discipline (regional geography), as regions are consistently studied in the whole field of geography. Regional geography is thus not necessary, but regions are what is needed in geography (MacLeod, Jones 2001). Regional geography can still be substituted by using regions as a delimitation of where other disciplines should be applied. The strength of regional geography, however, is in its complexity of synthetizing such pieces of knowledge, analysing them through a perceptive approach and allowing for the historic-geographical context of development in the studied region. Nobody but "complex" regional geographers can adopt such an approach which is crucial to not only understanding the formation process, existence and functioning of a region, but also to applying it, for example, in regional development.

When perceiving the region as a social construct, the strengths of such an approach include the following:

- The nomothetic character of such an approach, which is achieved by providing an explanation of processes and contexts; this is a significant methodological contribution. Contexts and processes enable a better understanding of functioning of regions and thus predict their future changes.
- Focus is given to those social topics, the significance of which within the region is growing constantly.
- A greater emphasis is put on those concepts which were neglected in regional geography in the past: political power and the whole of politics; social differences and social changes; global and local scale etc. That enables a better understanding of the current state of a region.

It is necessary to point out that weaknesses include, in particular, the following:

- Nature is missing; there is a non-complex character;
- Too much emphasis is given to social problems.
- Weaknesses relate to, in particular, the somehow reduced character of a region (the region is not so complex).
- Solutions to problems in a particular region created and suggested within new regional geography research cannot be fully transferable to solutions of similar problems elsewhere (due to specific conditions and time-space context).

### 4.2 The view presented by traditional regional geography

Understanding a region as a social construct has some weaknesses. It is obvious that the importance of society is growing – and as a result the region as a social construct is becoming more and more important. Despite that, the role of nature cannot be ignored (global warming, natural hazards, etc.). Within regional differentiation, nature is still the real power. The division of Canada into heartland and hinterland cannot be explained only by communication connections and economic advances, as they themselves are a result of climatic conditions.

A different understanding of the concept of the region is questionable. The increasing influence of reductionism in regional geography may be subject to criticism. Not only is the complexity of the region reduced, also the social component itself (the role of excluded minorities and different social communities is overvalued). Social sciences and geography still reflect social reality and now anticipate it, and they bring their own moral criteria to this. The identity of a region and region formation, as a theme, has been overestimated. Geography rejects tradition, it is "revolutionized". A positivist "epistemological turn" led to the formalization of the region; since the 1990s, an "ontological turn" has led to, it seems, growing vagueness and "mistiness" of geographical texts (see the increasing incomprehensibility of the fourth and fifth edition of *The Dictionary of Human Geography*). The traditional regional-geographical characteristics provide a more balanced, more complex, more usable (for planning etc.) and more vivid image of a region.

As to the traditional approach (the region in the sense of traditional geography), its strengths include the following:

– a complex approach; well-balanced characteristics of individual spheres and topics; a systematic approach
– focus is given to central (main) topics;
– it is "demanded" by the public (a growing demand for regional information);.

The weaknesses of traditional regional geography include the following:

– its descriptive character;
– little emphasis is given to society and to social topics;
– static characteristics of the region.

### 4.3 Towards a more complex regional geography

The development of knowledge may be perceived as evolution, as a gradual addition of new ideas, contributions, methodologies, and procedures. Regional geography and the concept of the region may thus include contributions from spatial science as well as humanistic and radical geographies. They may also accept contributions from social constructivism. It is easier to understand a region when accepting humanistic-geographic concepts of topophilia, topophobia (Tuan 1974), the sense of place, and placelessness (Relph 1976); Marxists' concepts of social justice in the city and in rural areas (Harvey 1973); as well as the impacts of globalization and postmodern cultures on local environments and communities (Savage, Bagnall, Longhurst 2005), etc.

There are strong examples of "good regional geography" (more balanced and complex, more aimed at the most important phenomena) in the history of geography: Jordan's *Texas* emphasized the confluence of cultures (Jordan, Bean, Holmes 1984); Harm de Blij presented his deep understanding of the world by applying geographical concepts to world regions (de Blij, Muller 2010). Such regional geography can provide more complex studies of society, as well as studies focusing better on central problems and explanation.

Dov Nir's conception of regional geography (Nir 1990) is based on systems theory. "Society and its physical environment is not a dichotomy: each is part of a whole, a *system*." (Nir 1990: 8). Dov Nir introduces the concept of the region as a holon, "when viewed from the inside it is something closed, something final and defined, but when viewed from the outside appearing as part of something larger" (Nir 1990: 25). Dov Nir introduces the region as a system with phenomena that are components of a whole, with relationships between components, and relationships between components and their environment; system is more than the sum of its components. And Nir's model of a systemic region is a way to study "hidden factors" (ibid. p. 103). Instead of providing an exhaustive characterization of all the elements, a focus on the central issue is proposed (Nir 1990: 39; Baranskij 1953).

The authors present several proposals that are aimed towards better characteristics of regions:

1. Regions are complex and holistic in the sense of physical-geographical – human-geographical unity.
2. A region is an open system with its own structure and relations between its parts and components as well as relations between the region and its environment.
3. Emphasis should be laid not only on a detail description of the region, but also on the central issue and on the most important phenomena.
4. Regional analysis includes all the basic geographical spheres (natural, economic, cultural, social and political system); sub-spheres are not a must. Social sciences and new regional geography stress the importance of social factors and processes; social factors and processes (and relevant processes and actors) should be incorporated into regional-geographical research.
5. Characteristics of a region can be made "more exact" by including the processes, contexts and transformation, and by formulating research questions that would lead to explanation and understanding (Kasala 2014).
6. Regional geography must be more relevant, more practice-oriented, should fulfil public expectations and provide vivid descriptions.

Regional-geographical characteristics may be identified by analyzing several "layers" gradually. Older approaches, which focus on the process of transformation, are of "Vidalian style" (i.e. they see the country-and-town symbiosis in the phases of historical succession [Wooldridge, East 1967: 158–159]) or they are in the form of Whittlesey's concept of sequent occupance. Sequent occupance of Southern California means the gradual transformation of the landscape in four stages: aboriginal – Spanish – American – international era. Niko Lipsanen's Master's thesis (Lipsanen 2001) offers three levels of analysis: the naturalistic analysis of Roseau (position, structure, function, texture); existential analysis (visiting, dwelling, changing); and synthesis (districts of Roseau, Roseau as a place). A triple model of place (Matlovič 2007) is composed of place as the filling of a part of time-space (physical and technical sphere components); as an arena, process – social construction (social sphere components); and as meaning, identity (noosphere and cyber sphere). John Agnew (2005: 89) presents an idea of three components of place: place as a location or a site; place as a locale (a setting for everyday activities); and place as a sense of a place (a place of identification).

"The ultimate goal of a regional descriptive synthesis was achieved through a thematic "layering" of subject matter, extending from the physical environment through several layers of human intervention." (Pudup 1987: 1) In conclusion we would like to propose a scheme of layers of regional-geographical analysis. The analytical part of our research consists of three layers of analysis. The first layer is the "objective region". This layer provides an insight (detailed information) and broad understanding (comparative, processual and contextual). The second layer focuses on the personality of the region – by identifying its specifities, its central phenomena. And the third layer deals with subjective experience, sense of place, identity. Those three layers enable a synthesis and provide a deep understanding of the region. They can be a good basis for regional development and other applications.

## 5. Conclusion

"*Regional geography cannot divorce itself from the empirical world. If it did, it would be likely to become a bloodless Platonic Universe of Ideas, merely producing theories for their own sake.*" (Wood 1999: 205)

"*The highest form of the geographer's art is producing good regional geography – evocative descriptions that facilitate an understanding and an appreciation of places, areas and regions.*" (Hart 1982: 2)

One of the contributions of regional geography is that it defines regional differentiation and explains it. Changes within any scientific discipline are necessary; yet changes do not necessarily mean certain progress. Growth of knowledge is an evolutionary process. Our current knowledge is based on contributions which we "achieved" in previous periods. Traditional as well as new regional geography – both of them have advantages and disadvantages. Each of them can benefit from the other.

A comparison of these two basic approaches to the concept of region is one of the contributions of this article. By comparing the two approaches the authors present a brief proposal of a more complex approach in regional geography, showing that these two approaches are complementary, which is a benefit. Traditional regional geography is more complex, as it allows a better understanding of a region. On the other hand, new regional geography (as an example of socio-constructivist approach) is a contribution to geographical methodology, because it facilitates explanation by using contexts and processes.

In the introduction, the authors formulated several research questions. The 1st research question was: "How has the meaning (understanding) of the concept of the region developed over time?" The most typical changes in the meaning of the concept of the region included a loss of complexity as well as shift to a more social understanding. Regional geography gradually "split" into two main directions: traditional geography and new regional geography. The 2nd research question was: "How was the concept of region perceived by significant geographers?" The article focuses on key personalities – geographers and on their understanding of region. Carl Ritter looked for unity within diversity, interconnections and interrelations; for Ritter, human and physical worlds are inseparable. Starting with Paul Vidal de la Blache, nature is perceived as a "product of the culture". Vidalian French regional geography was holistic and complex. Carl Ortwin Sauer researched the landscape (i.e., region) by applying a morphological analysis which was composed of both analyses: analysis of the natural landscape and analysis of the cultural landscape. Richard Hartshorne understands the region as a unique area and as a mental construct. Hartshorne's chorology is typical of his strong character of unity.

The traditional understanding of the region underwent changes in its meaning in mid-twentieth century. Derwent Whittlesey (1954) understands a region as a formal region; and geography, as a spatial science, leaving the idea of a unique region completely behind, and investigating regional patterns, regularities, and interactions. Anssi Paasi and other representatives of the new regional geography understand the region as a social construct. The concept of the region presented by the Israeli geographer Dov Nir (1990) is based on systems theory. The authors identify the most important strengths and weaknesses (research question No. 3: What were the weaknesses and strengths of the main approaches?). The region as a social construct has advantages: a nomothetic approach with explanation based on processes and contexts; a strong emphasis on political and social themes; weaknesses (disadvantages) are the problem of transferability of solutions from one region to others; a non-complex character due to leaving out nature. The strengths of the traditional concept of a region are its complex and systematic approach; focus is given to central (main) topics, while the weaknesses of this traditional understanding of a region are its descriptive character and the static characteristics of the region with little emphasis placed on society. The 4th research question was: "What are the main contributions of the main approaches?" The main advantages as and contributions of the traditional concept of a region include complexity and a focus on the main phenomena and specifities of region. The main contributions of new regional geography (the region understood as a social construct) include a greater emphasis given to social topics and methodological contributions (processes, contexts). The answer to the last research question ("How can the positive aspects of the two approaches be used when characterizing a region?") leads us to an attempt to find more optimal characteristics of a region.

As analyzed in the last part of the article, a more complex regional geography is based on systems theory (Nir 1990), a holistic complex understanding of a region (Nir 1990) as well as a socially produced and reproduced region (Gilbert 1988; Paasi 1986), and thus uses also new methodologies focused on processes and contexts (Johnston, Sidaway 2004). "Layering" of the research (see also Lipsanen 2001; Matlovič 2007; Agnew 2005; Pudup 1987, 1988) provides a deeper understanding of a region. The authors present "a model" with three layers of analysis, which include three ways of understanding (*verstehen*): 1) an "objective" region with comparative, processual and contextual understanding; 2) the personality of a region understood through its specifities, central phenomena; 3) the subjective meaning of a region understood through its identity, sense of place and subjective experience.

## Acknowledgements

The article is supported by the VEGA project "Social, economic and environmental determinants of regional development and transformation: a regional geographic approach" (No. 1/0540/16) and the Czech Science Foundation project "Historical Geography Research Centre" (No. P410/12/G1sx13).

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# ESTABLISHING A MULTI-PROXY APPROACH TO ALPINE BLOCKFIELD EVOLUTION IN SOUTH-CENTRAL NORWAY

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**ABSTRACT**

Blockfields in high latitude mountain areas are a wide spread proxy for glaciation history. Their origin is debated since decades, especially in south-central Norway, where glaciation had a major global climate implication. Some authors explain old blockfield features by protection of cold-based ice, others claim they persisted as nunataks during the LGM (~20 kyr), or were formed throughout the Holocene. In order to clarify the origin of alpine blockfields we established a multi-method approach to combining lichenometry, stratigraphy, granulometry, and geochemistry (XRD, XRF). Our lichenometric dating results in conjunction with our factors indicate landscape stability for at least ~12.5 kyr. Frequent climatic shifts are evident in our profiles by varying color, LOI content and grain sizes. On the basis of geochemical analyses we were able to identify a long-term (chemical) weathering history and in situ blockfield formation. The field evidences and the climatic setting of the study area leave the possibility that our location was not covered by cold-based ice during the Late-Quaternary.

**Keywords:** glaciation history; Scandinavia; mountains; geochemistry

Received 27 February 2017; Accepted 18 October 2017; Published online 21 November 2017

## 1. Introduction

For more than 100 years there has been an ongoing debate about the glaciation history of Scandinavia, particularly in south-central Norway (Blytt 1876; Lagerbäck 1988; Mangerud 1991; Nesje et al. 2007). Glaciation history and former ice sheet configurations are important aspects in terms of understanding atmospheric as well as oceanic circulation and temperatures, sea level changes, thermohaline circulation and glacial landform evolution (Winguth et al. 2005; Goehring et al. 2008; Sejrup et al. 2009). The glaciation history with regard to glacial cycles during the Quaternary is fairly known (Mangerud 2004; Linge et al. 2006). However, the knowledge about ice thickness, ice thickness evolution, flow configuration and englacial thermal conditions are very limited (Winguth et al. 2005; Goehring et al. 2008). With the help of relict non-glacial landforms (for discussion see Goodfellow 2007) such as blockfields it is possible to quantify Quaternary glacial erosion, reconstruct landscape development and ice sheet properties (Goodfellow 2007; Ballantyne 2010). Typically, blockfields consist of in situ weathered angular blocks and rocks. The surface rocks frequently cover a soil matrix, mixed with different grain sizes (Rea et al. 1996; Ballantyne 2010). Despite the long debate, the age of blockfields mostly remain ambiguous. Some authors favor the Neogene-origin model (Nesje et al. 1988; Marquette et al. 2004; Fjellanger et al. 2006) where blockfields developed during warmer than present climate. Others claim that blockfields are Quaternary periglacial features (Dredge 1992; Ballantyne 1998; Goodfellow 2012), where blockfields are formed through a combination of physical and chemical weathering, independently from Neogenic influences. The role of blockfields during recent glaciations is dominated by three schools of thought which either claim 1) that blockfields are Holocene features induced by frost shattering or frost sorting (Dahl 1966), 2) blockfield preservation by a cold-based, non-erosive ice sheet (Sugden and Watts 1977; Lagerbäck 1988; Kleman and Borgström 1990; Kleman 1994; Fjellanger et al. 2006) or 3) that blockfields represent ice-free areas (nunataks) within a thin ice sheet configuration with selective glaciations (Nesje et al. 1988, 2007; Nesje and Dahl 1990; Brook et al. 1996; Ballantyne et al. 1997; Landvik et al. 2003).

A mountain over which the above mentioned issues had been discussed is Blåhø (Nesje et al. 1994; Goehring et al. 2008; Strømsøe and Paasche 2011). Previous studies do not include systematical investigations of soil horizons which are an important source of palaeoenvironmatal information. In this study we are combining several methods to provide new information on the glaciation history of Blåhø. Lichenometric dating can be a useful relative dating tool in arctic-alpine environments where organic based dating techniques are not suitable or fail (Trenbirth 2010). Despite of successful application of lichenometric dating (e.g. Matthews 2005), the reliability of the technique is fundamentally questioned (e.g. Jochimsen 1973; Osborn et al. 2015). Certainly, caution has to be paid designing the sampling strategy, and results have to be interpreted carefully. Comprehensive stratigraphic, granulometric and geochemical soil analyses

https://doi.org/10.14712/23361980.2017.18
Marr, P. – Löffler, J. (2017): Establishing a multi-proxy approach to alpine blockfield evolution in south-central Norway
AUC Geographica, 52, No. 2, pp. 219–236

help to determine a time integrated weathering history and long-term weathering trends (Strømsøe and Paasche 2011). The role of chemical weathering is believed to be significant since the seminal paper of Rapp (1960). However, only recently the important role of chemical weathering in cold climate conditions is stressed (Hall et al. 2002; Darmody et al. 2005). Moisture availability rather than temperature is the limiting factor of chemical weathering (Hall et al. 2002). The state of chemical weathering gives information about palaeoenvironmental linkages (Nesbitt and Young 1982; Marquette et al. 2004). Chemical weathering is a slow process in cold-dry environments. For soils with advanced chemical alteration a long period of pedogenesis and weathering is indicated (Allen et al. 2001). Chemical processes are important weathering agents, they weather material to fine silt and clay, whereas mechanical weathering mostly produces grain sizes larger than medium silt (Strømsøe and Paasche 2011).

Full scale Fennoscandian ice sheets, covering most of the peninsula were documented within the Quaternary, around 40 glaciation cycles were recorded (Kleman and Stroeven 1997; Kleman et al. 1997). Denton and Hughes (1981) claimed that the ice thickness in Scandinavia reached 2–3 km. However, there are indications that the last major ice sheet was probably thinner than assumed, multi-domed and thinned towards the east (Nesje and Dahl 1990), without reaching all mountain peaks in western Norway (Follestad 2003; Winguth et al. 2005). This is sustained by pre-Quaternary landforms conditioning glacial behavior, where already existing valleys acted as trajectories for new ice flow, leaving high summits untouched (Sugden and Watts 1978). Skåla (1848 m a.s.l.) is thought to have escaped the last glaciation (Brook et al. 1996), Folldalen and mountain plateaus in Dovrefjell are supposed to have been ice free during the Younger Dryas (~12.5 kyr) (Dahl et al. 1997; Mangerud 2004). In concert with this, recent studies show that glaciation histories worldwide differ from previous assumptions, as parts of Greenland and Svalbard were ice-free during extended periods of the Pleistocene and the LGM (Landvik et al. 2003; Schaefer et al. 2016).

The aim of our study was to shed light onto the weathering history of a blockfield at Blåhø by applying a multi-proxy approach, including five different methods. As such, the key contribution of our paper is to correlate blockfield weathering characteristics to glaciation history of south-western Norway.

## 2. The study area

Blåhø (1618 m a.s.l.) is located in south-central Norway (61°53′51 N, 9°16′58 E) along Gudbrandsdalen between Jotunheimen in the south-east and Rondane in the west (Figure 1). The mountain splits into three lower individual peaks, Rundhø at 1556 m a.s.l., Veslrundhø at 1514 m a.s.l, and Storhøi at 1455 m a.s.l. with gently undulating surfaces (Figure 2). The summit plateau of Blåhø is surrounded by gentle slopes to the north, west and south and a steeper slope towards the east. The summit ridge descends to the east, later splitting towards south-east and north-east. Bedrock outcrops are scarce and frost shattered.

The climatic setting is characterized by relatively strong continentality. With a mean annual air temperature (MAAT) of ~−4 °C (Strømsøe and Paasche 2011) and a mean annual precipitation (MAP) between 300 and 400 mm/yr in the valleys, the area represents one of the driest localities in Norway (Moen 1998). Recent data from permafrost boreholes next to our profiles indicate a mean ground temperature (0.05 m depth) of 0.9 °C and 1.0 °C from 2008 to 2009, respectively 2009 to 2010. The mean ground temperature at 10 m depth was 0.7 °C from September 2008 to August 2010. The snow depth (≥ 5 cm) reached >140–269 days and >140–271 days from 2008 to 2009, respectively 2009 to 2010. In the same time range the active layer thickness reached 7 m to 6 m (Farbrot et al. 2011).

The Precambrian bedrock largely consists of quartz; the summit can be lithologically divided into two parts: meta-conglomerate and meta-sandstone are present at higher, respectively lower slopes (Sigmond et al. 1984; Goehring et al. 2008; Farbrot et al. 2011). The area from the summit to about 1500 m a.s.l. is piled with autochthonous blockfields. The highly weathered and lichen encrusted rock surfaces indicate current surface stability. No signs of glaciofluvial meltwater channels were found. The middle-alpine vegetation on the ridges and peaks is dominated by lichens and graminoids. From 1500 to 1300 m a.s.l. mostly allochthonous blockfields are present (Nesje et al. 1994). On lower slopes exposed bedrock surfaces with clear glacial striations can be found.

In order to test variations of soil horizon and weathering characteristics three pits were manually excavated to log vertical soil profiles (Figure 3). The first (P1) was dug at a side summit of Blåhø (61°54′12 N, 9°16′36 E; 1518 m a.s.l.) with a north north-eastern orientation and an inclination of 4°–6°. This minimizes the likelihood of material removal or addition (Allen et al. 2001). P1 is surrounded by relatively flat topography which is smoothly rising towards the summit in the south and gently sloping towards the other sides. P1 has a depth of 160 cm, eight horizons were labeled from the bottom in ascending order from 0 to 7. On the summit two erratics were identified.

The other two pits (P2a, P2b), 1.5 km west of Blåhø at the south-eastern slope of Rundhø, were labeled to three horizons. The slope is characterized by periglacial patterned ground phenomena (blockstreams) with south-western orientation and 12° inclination (Figure 4). The pit of P2a with a depth of 140 cm is located in the blockstream (61°54′50 N, 9°14′55 E; 1467 m a.s.l.), P2b is 110 cm deep and directly located next to the blockstream

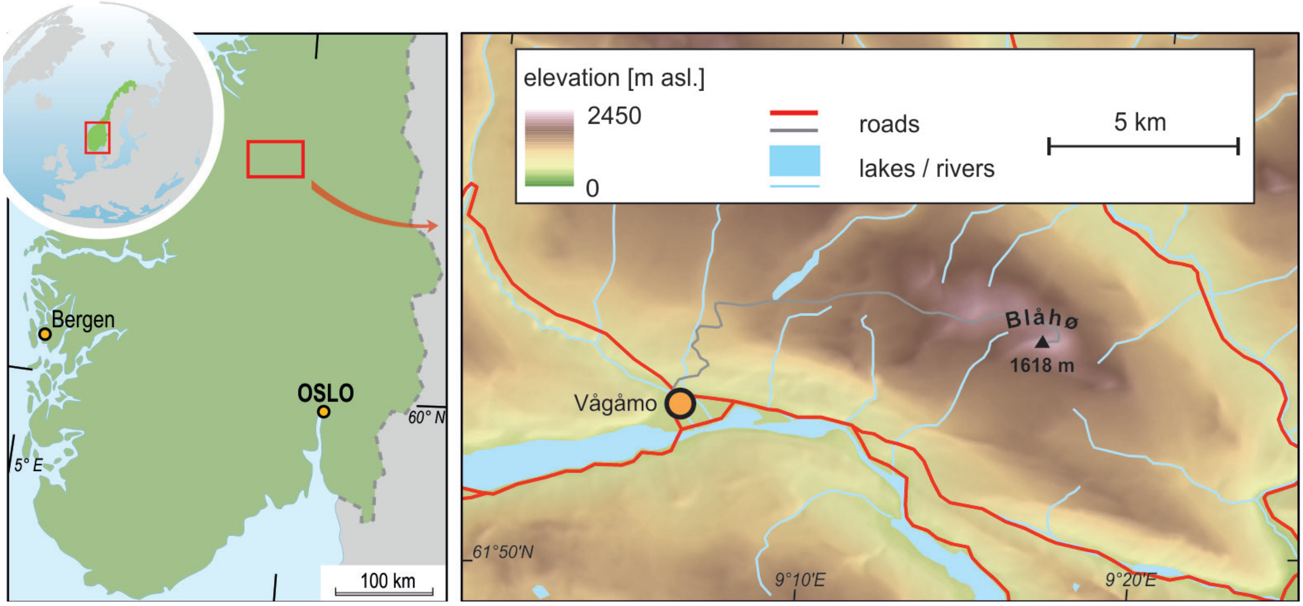


**Fig. 1** Map of the study area in south-central Norway; modified after Pape & Löffler (2017).

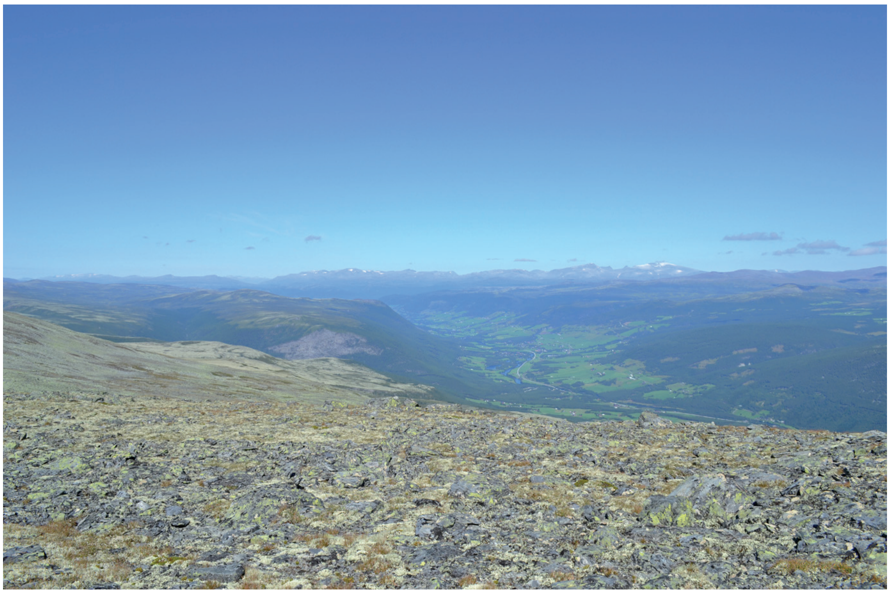

**Fig. 2** View from the blockfield towards northwest.

## 3. Methods

The multi-proxy approach was designed to avoid limitations of single methods and benefit from synergetic effects combining different methods. Estimated surface ages from lichenometric dating can give indications about the surface stability during the late Holocene. Stratigraphical units, in combination with granulometry and organic content; can provide information about climatic circumstances they developed in and past weathering conditions they were exposed to. X-Ray fluorescence (XRF) and X-Ray diffraction (XRD) reveal information about the (chemical) weathering history, weathering indices about on age and provenance of the material.

### 3.1 Lichenometric dating

In this study the green crutose lichens of *Rhizocarpon subgenus* (often described as *Rhizocarpon geographicum*) are investigated. They are abundant, easily recognizable and have often been used to determine rock surface ages successfully (Trenbirth 2010; Armstrong 2011). Lichens were measured in a sufficient study area of 225 $m^2$ around the pits (Bradwell 2009). In sum, 72 randomly selected lichens were measured at their longest axis to the nearest millimeter (P1 n = 33, P2 n = 39). The measurements were performed within uniform lithological setting and undertaken by one person within two hours at each site. To ensure measurement consistency, only lichens on near horizontal surfaces on the upper side of stable boulders

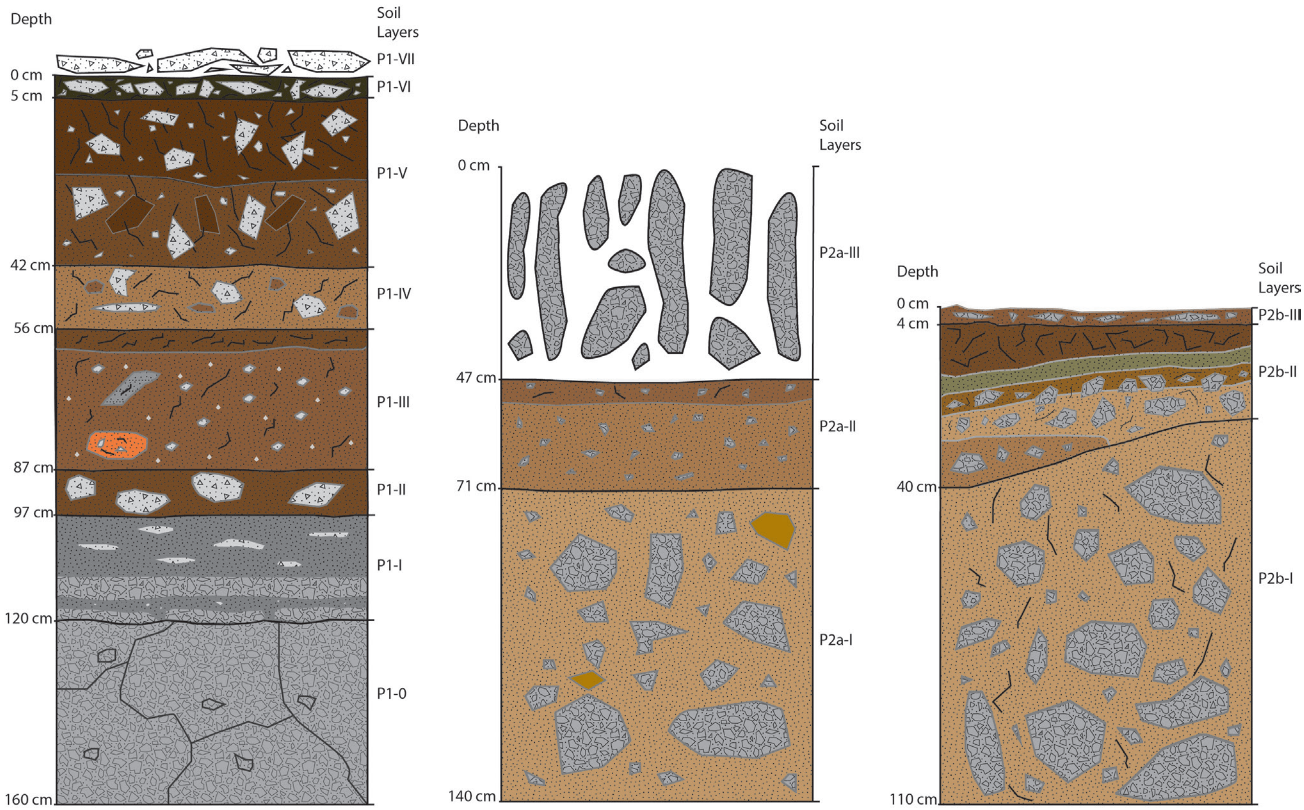


**Fig. 3** Schematic stratigraphic profiles of P1 (left), P2a (center), P2b (right).

**Fig. 4** View from top of the blockstream towards south.

(> 0.3 m) or on bedrock were measured. It was ensured that all lichens had a mostly uniform inclication towards north (P1) and south (P2). All measured lichens were free of weathering features, (close to) circular and differentiable individuals with no coalesce to other lichens (Figure 5). Standard statistical treatment was carried out (Table 1). The mean of the five largest lichens were used as suggested by many authors (e.g. Shakesby et al. 2004; Matthews 2005). As the rock surface age in this study is of unknown age, the regional lichenometric dating curve from eastern Jotunheimen (Matthews 2005) was used. This has already been applied successfully in south-central Norway (Winkler et al. 2003; Shakesby et al. 2004). No indications for lichen growth variations between regions in southern Norway were found so far (Trenbirth and Matthews 2010). The estimated growth rate for old surfaces in eastern Jotunheimen is 0.45 mm/yr and is applied here due to spatial proximity (Matthews 2005). However, Harris et al. (1987) present growth rates in Jotunheimen of 0.14 mm/yr at 1575 m a.s.l. in Jotunheimen. Growth velocities are negatively affected by cold-dry micro-scale environmental conditions (Beschel 1961; Webber and Andrews


**Fig. 5** Lichen measurement (Picture P. Marr).

1973). Hence, the results of this study should be considered as minimal ages (Matthews 1994). Lichens require long colonization time and show nonlinear growth rates (Benedict 1967; Jochimsen 1973). Through prolonged lichen growth it is possible that the present lichens are not original colonizers as mortality rates range between 0.38 and 5.08 % in a 19 year interval (Trenbirth and Matthews 2010; Armstrong 2016). Many climatic and ecological factors influence the behavior of lichen colonization, growth, growth rates and mortality to an uncertain extent.

### 3.2 Stratigraphy, Granulometry and LOI

Soil horizons were classified at each profile and a mean of 2.8 kilograms of representative bulk samples (including soil and skeleton) were taken from each horizon. All following measurements were carried out with representative samples of each horizon. P1 was divided into eight horizons, P1-VII (surface sample), P1-VI (0–5 cm), P1-V (5–41 cm), P1-IV (42–56 cm), P1-III (56–87 cm), P1-II (87–97 cm), P1-I (97–120 cm), P1-0 (120–160 cm). Each P2a and P2b were labeled with three horizons, P2a-III (0–47 cm), P2a-II (47–71 cm), P2a-I (71–140 cm), P2b-III (0–4 cm), P2b-II (4–40 cm), P2b-I (40–110 cm). The information on color (Munsell 1994), soil matrix, distribution and configuration of rocks were processed into comprehensive illustration (Figure 3). Samples were air dried and the collected soil matrix from each horizon was sieved and divided into fine matrix (< 2 mm) and skeleton fractions (> 2 mm). Organic carbon content was determined by loss on ignition (LOI) at 550 °C as described by Heiri et al. (2001). 5 g of air dried fine matrix was heated to 105 °C for twelve hours and cooled in the desiccator. Subsequently, samples were heated to 500–550 °C in the muffle furnace for ten hours. After cooling in the desiccator, the weight loss was measured and the organic content calculated (in %). Each sample was measured twice. Two microspoons of fine matrix from each horizon were subject to grain size analysis, with a four time repetition measurement each. Samples were prepared according to DIN 18123 and calculated with the Mie-Theory (Markl and Marks 2008). The laser light scattering spectrometer (HORIBA LA-950) was used for granulometric analysis.

### 3.3 Geochemical analyses

XRF measurements were carried out with the PANalytical Axios FAST spectrometer. Sample preparation followed standard procedures. Fine and skeleton samples from each horizon were analyzed separately. XRD was measured with the Bruker AXS, D8 Advance to identify and quantify primary (quartz, plagioclase, mica, amphibole) and secondary minerals (kaolinite, chlorite and gibbsite) (Marquette et al. 2004; Goodfellow et al. 2009). Results below 10 ppm were excluded from the analysis (Sheldon and Tabor 2009). Diffractograms generated by software applications create semi quantitative data of mineral percentages (Tucker 1996). Illite and muscovite cannot be distinguished in the diffractogram, therefore the superordinate term mica is. The term plagioclase is used to include different feldspar representatives. Site-related geochemical gains and losses in mass transfer can be illustrated by applying the isocon technique. Relating the amount of mobile to immobile elements between bedrock and fine matrix (Grant 2005), based on the assumption that the bedrock is unweathered. Mobile elements in fine matrix such as Sr, K, Mg, Ca and Na are expected to decrease in comparison to the bedrock and drop underneath the immobile element isocon line. Immobile elements as among others Nb, Y, Ti, Th, Si and Al are expected to be similarly modified than the bedrock and located on the line (Grant 2005; Goodfellow et al. 2009).

Weathering indices such as CIA (Nesbitt and Young 1982) and WIP (Parker 1970) were applied to quantify the severity of chemical alteration and/or geochemical differences in soil profiles (Birkeland 1999; Price and Velbel 2003; Darmody et al. 2005). Molecular proportions were used to calculate the indices. The WIP (equation 1) comprises only mobile elements while CIA (equation 2) assumes Al to be immobile. WIP values decrease with increased weathering, CIA behaves vice versa.

$$WIP = \left(100 \times \left[\left(\frac{2Na_2O}{0.35}\right) + \left(\frac{MgO}{0.9}\right) + \left(\frac{2K_2O}{0.25}\right) + \left(\frac{CaO}{0.7}\right)\right]\right) \quad (1)$$

$$CIA = \left(100 \times \left[\left(\frac{Al_2 0_3}{Al_2 0_3 + CaO + Na_2O + K_2O}\right)\right]\right) \quad (2)$$

The Ti/Zr ratio (equation 3) is used to determine the connectivity of the sample to the chemical composition of the parent material (Maynard 1992).

$$\frac{Ti}{Zr} = \frac{\left(\frac{Ti}{Zr_{regolith}} - \frac{Ti}{Zr_{parent}}\right)}{\frac{Ti}{Zr_{parent}}} \quad (3)$$

## 4. Results

### 4.1 Lichenometric dating

Histograms for lichen size distribution around P1 and P2 (Figure 6) show bimodal distributions with several peaks, the populations are not normally distributed. The minimum and maximum values and statistical parameters are listed in Table 1. The statistical calculations show comparable mean, median and standard deviation. The values are positively skewed. The majority of lichen diameters vary between 100 and 140 mm. However, six lichens at P1 and seven at P2 have a larger diameter. The mean diameter of all lichens and the five largest lichens are identical at both pits (Table1, Table 5).

**Tab. 1** Lichenometric dating statistical results.

| | P1 | P2 |
|---|---|---|
| All data | | |
| No. of observations | 33 | 39 |
| Maximum size (mm) | 244 | 235 |
| Minimum size (mm) | 47 | 54 |
| Mean (mm) | 118.97 | 116.31 |
| Median (mm) | 110 | 106 |
| Standard deviation | 48.23 | 45.27 |
| Standard error of the mean | 8.4 | 7.25 |
| Confidence interval of the mean (95%) | 17.1 | 14.68 |
| Skewness | 1.19 | 1.05 |
| Kurtosis | 1.1 | 0.21 |

### 4.2 Stratigraphy

The pits show similarities concerning lichen cover, presence of soil horizons, relatively high amount of fine matrix and the absence of till. Key differences are the amount of soil horizons, pits from Rundhø are more disturbed, complicating their interpretation. P1 is characterized by clear soil horizons with distinct color differences and a recurring color pattern from light to dark. The surface horizon P1-VII is represented by mostly angular rocks without structural orientation. Top soil horizon P1-VI has dark brown color (5Y 4/1), the darkest in the profile. P1-V can be subdivided in a dark brown greyish upper part (2.5Y 4/1) and a slightly lighter lower part (2.5Y 5/1). A cryoturbation soil pocket was visible as material from the upper part of the horizon migrated downwards and was deposited in the matrix of the lower lying horizon. Strong root penetration, mixture of big and small, partly angular rocks is apparent. P1-IV has a lighter brown color (5Y 7/3) and high share of skeleton. P1-III has light brown-greyish color (2.5Y 5/3), darkening towards the upper part. It is characterized by small rocks, low amount of roots and the lowest skeleton proportion of the profile (Table 3). P1-II exhibits a brownish color (2.5Y 4/3) with large rocks. A broad color change to grey appears towards P1-I (7.5Y 7/2). The lowest horizon P1-0 is characterized by a light grey color (7.5Y 7/1) and very big, flat rocks dominating the compact matrix with the highest skeleton share. Most likely the bedrock was reached, as it was not possible to dig deeper. Top horizon P2a-III shows big flat rocks, rounded by periglacial processes. P2a-II is characterized by a light brown color (2.5Y 5/4) without big rocks. The upper part has a brown humic layer. P2a-I displays light ochre brown (2.5Y 6/3) with big and small rocks. P2b-III surface horizon has small flat stones within grass patches. The upper part of P2b-II has a humic layer, strong root penetration and mostly light brown color (2.5Y 6/4), darkening towards the lower part of the horizon and gets increasingly heterogeneous. The color of P2b-I changes from a dark brown (2.5Y 4/6) in the upper part to a light brown (2.5Y 5/6) at the bottom, with mostly big rocks.

### 4.3 Granulometry and LOI

A repetitive trend is observable in the profile as the declining amount of silt from P1-I to P1-II and P1-IV to P1-V are comparable (Table 2). From P1-I there is an increase of the sand fraction, peaking at P1-II, subsequently declining until P1-IV where values are comparable to P1-I. From P1-IV to P1-VI silt values again decrease whereas sand is increasingly dominating. The grain size distribution of P2a is characterized by an increasing sand share with depth, in contrast to all other profiles, the relatively high amount of clay which increases with depth. The grain size distribution of P2b shows

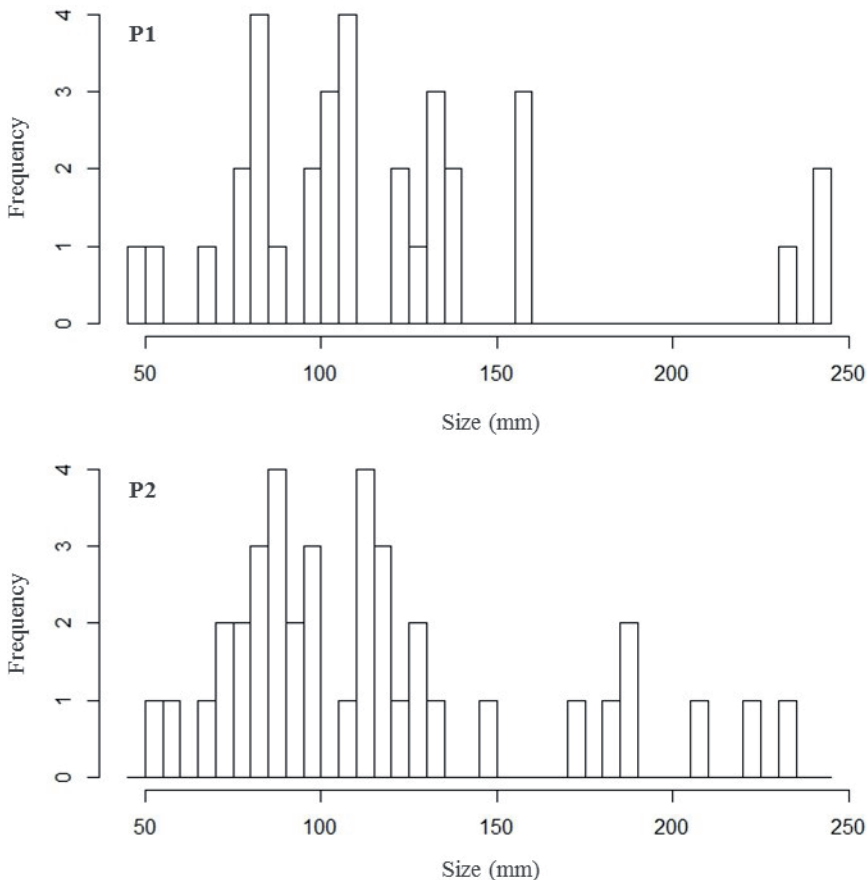


**Fig. 6** Histograms plotted with a class size of 5 mm with data from P1 (top) and P2 (bottom).

**Tab. 2** Grain size distribution of fine matrix from Blåhø and Rundhø.

| | Grain size (%)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample | clay (<2 µm) | f silt (2–6.3 µm) | m silt (6.3–20 µm) | c silt (20–63 µm) | f sand (63–200 µm) | m sand (200–630 µm) | c sand (630–2000 µm) | clay/silt ratio |
| P1-VI | 0.64 | 5.83 | 20.50 | 33.82 | 15.16 | 13.47 | 10.59 | 0.011 |
| P1-V | 0.36 | 5.26 | 23.49 | 44.25 | 20.35 | 5.02 | 1.29 | 0.005 |
| P1-IV | 0.32 | 6.08 | 30.10 | 44.86 | 16.43 | 2.20 | 0 | 0.004 |
| P1-III | 0.34 | 5.06 | 23.17 | 43.03 | 18.93 | 6.19 | 3.27 | 0.005 |
| P1-II | 0.45 | 3.99 | 17.28 | 43.68 | 21.90 | 8.39 | 4.32 | 0.007 |
| P1-I | 0.43 | 6.48 | 28.77 | 42.98 | 15.26 | 3.56 | 2.52 | 0.006 |
| P1-0 | 0.73 | 7.61 | 27.71 | 39.13 | 15.16 | 6.86 | 2.81 | 0.010 |
| P2a-II | 0.88 | 5.60 | 15.56 | 38.12 | 31.41 | 6.95 | 1.48 | 0.015 |
| P2a-I | 1.81 | 3.55 | 6.27 | 27.77 | 36.65 | 21.36 | 2.59 | 0.048 |
| P2b-II | 1.30 | 5.10 | 11.39 | 32.48 | 29.04 | 13.57 | 7.12 | 0.027 |
| P2b-I | 1.14 | 3.59 | 8.04 | 33.94 | 33.22 | 14.69 | 5.37 | 0.025 |

* Grain size fractions: f, fine; m, medium; c, coarse

no distinct pattern. The clay/silt ratios from all samples are low (≤ 0.14).

The LOI fine matrix analyses of P1, P2a and P2b show generally low values (Table 3). The LOI values of all profiles increase towards the surface. P1 shows a deviation from this trend as it peaks first at P1-III, subsequently values decrease and consecutively rise to the peak at P1-VI.

## 4.4 Geochemical analyses

The results of the major element analysis from fine matrix and skeleton samples show strong similarities, skeleton samples, however, show higher variability (Table 3). It is difficult to identify trends for P2a and P2b as their horizontal zonation is limited and horizons incorporate more heterogeneous material. The comparison of

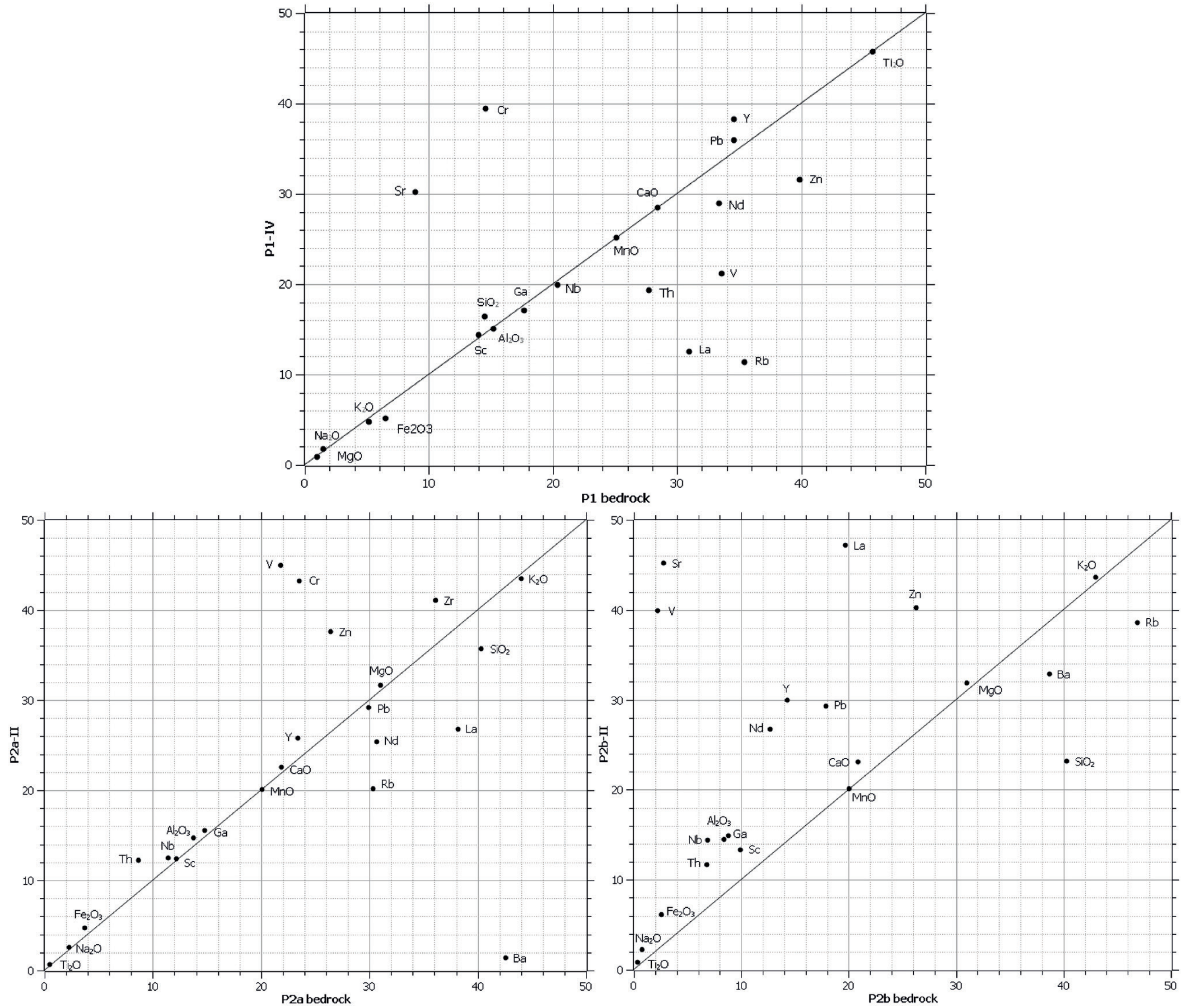


**Fig. 7** Isocon plots of element and mineral alteration between fine matrix and bedrock (P1-0, P2a-I, P2a-I) of Blåhø and Rundhø. The diagonal represents the immobile element isocon line. Elements above the line show a concentration increase, elements below were depleted. Element concentrations were scaled to fit in the plots.

geochemical gains and losses between fine matrix with skeleton samples with the isocon technique is illustrated in Figure 7. The displayed trends are comparable to other fine matrix and rock samples within the sites. The values of Ti, Na, Mn, Mg and K from all profiles are similarly altered and located on the isocon line. Rb was depleted in all profiles, whereas P2a/P2b samples show more similarities in enrichment and depletion of elements in comparison to P1.

In Figure 8, the values of weathering indices are plotted with soil horizons. There is little variability in the CIA results of fine matrix and skeleton samples of P1, except for P1-II and P1-IV where the fine matrix shows higher values than skeleton. The WIP values are in the range between 55.1 (P1-V skeleton) and 74.9 (P1-VII skeleton). The calculated Ti/Zr results are −0.2 (P1), 0.5 (P2a) and 0.1 (P2b).

Most trace elements show similar trends at P1. P1-IV is a point where trace elements in fine matrix show changing behavior (Table 3). Subsequently, a phase of stability of the fine matrix samples occurs after depletion from the surface. Many skeleton values show changes from P1-IV to P1-V, with an enrichment of most trace elements. The values generally show little variability, except surface and bottom horizons often show exceptional values. The fine matrix samples of P2a and P2b show limited variation. The skeleton values of P2a mostly increase from P2a-III to P2a-II and subsequently decline downwards. Generally skeleton values of P2b show more variability than fine matrix.

XRD data illustrate primary minerals in all samples. Clay minerals (Table 4) were found in fine matrix samples of P2a and P2b. Quartz is the dominant mineral in most horizons, followed by mica and plagioclase. The skeleton samples show more complex mineral distribution with more variations than fine matrix samples. At P2a and P2b more quartz is present in the fine matrix samples.

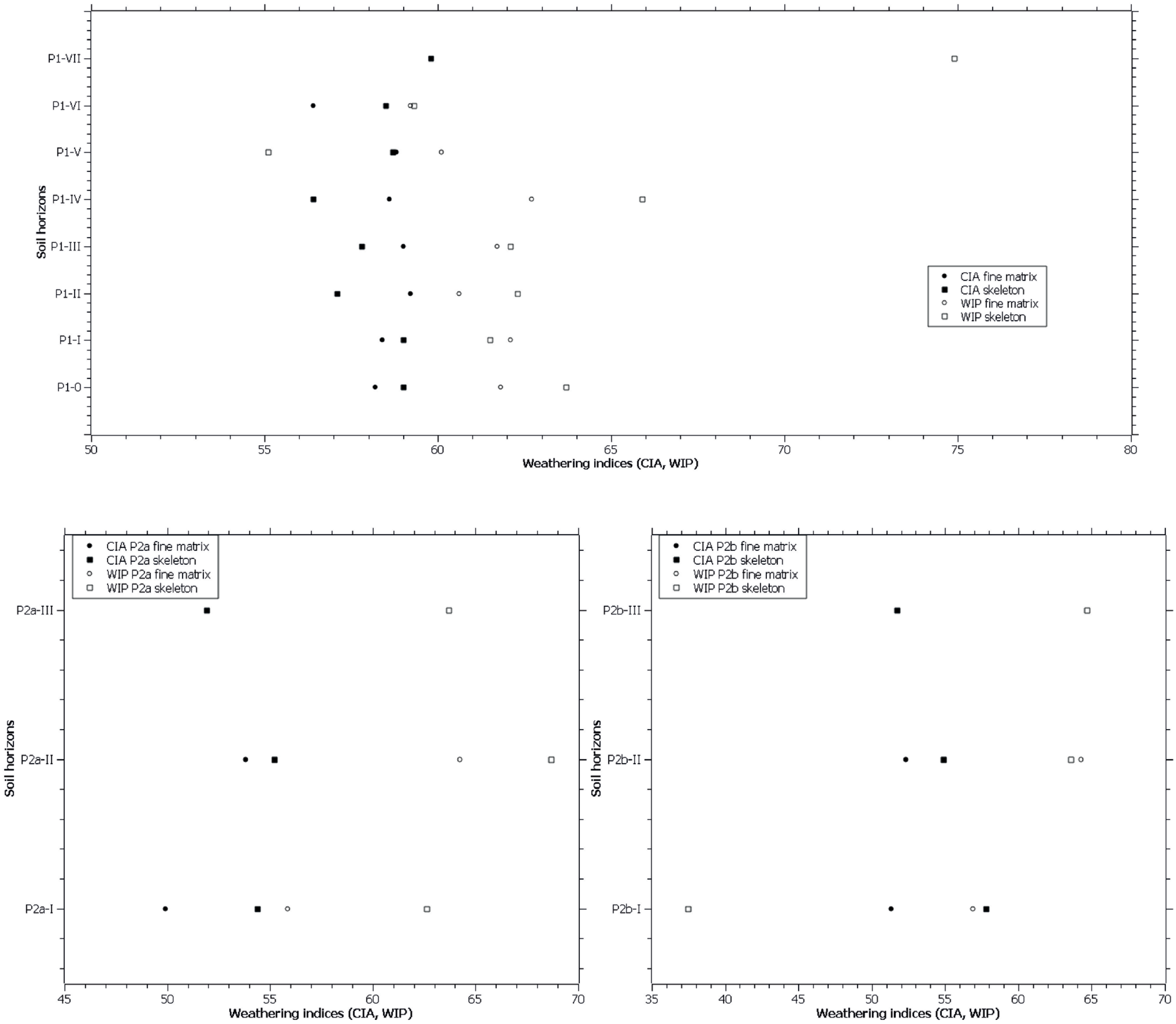


**Fig. 8** Weathering indices (WIP and CIA) of all profiles (P1, P2a, P2b) with depth. The indices were calculated for fine matrix (< 2mm) and skeleton fractions (> 2mm).

## 5. Discussion and conclusion

### 5.1 Weathering characteristics, geochemical distribution and profile properties

The information on palaeoenvironments conveyed from soils varies in accuracy due to the nature of horizons and the periods surveyed. Therefore, the results must be interpreted carefully. Our XRD and XRF analyses, granulometric results, and weathering indices indicate that chemical weathering has strongly modified the investigated soils. The suggested indicators for chemical weathering by Gouveia et al. (1993) and Goodfellow et al. (2009) are element mobility and low plagioclase values which are present in our profile. Element mobility is reflected in the relationship between silica and iron is an indicator for chemical weathering (e.g. Birkeland 1999). All samples show a fairly strong non-linear relationship (Figure 9; $R^2 = 0.63$; $\alpha < 0.01$), indicating gradual leaching of more mobile elements as silica in comparison to the more stable iron element (Birkeland 1999; Strømsøe and Paasche 2011). With progressed weathering high iron concentrations will be opposed by low silica values. The immobility of many mobile elements is likely connected to the longevity of weathering processes which reach quasi-equilibrium where the rate of chemical weathering is constant but low at present (Strømsøe and Paasche 2011).

Accumulated quartz in the fine matrix in comparison to skeleton samples can be explained by long-term in situ physical weathering. Our Ti/Zr results display negligible divergence between bedrock and soil matrix and support in situ formation (Strømsøe and Paasche 2011). In contrast to Ballantyne's (2010) assumption that soil horizons are usually absent in blockfields, they are well developed in our profiles. This also points to long-term and intense chemical weathering. WIP ratios of P1-V and P2b-I are

**Tab. 3** Concentration of major elements (%), trace elements (ppm) and material size (%) from fine matrix and skeleton samples.

| | | Size (%) | | Major Elements (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample** | **Type** | **<2mm** | **>2mm** | *$SiO_2$* | *$Al_2O_3$* | *$Fe_2O_3$* | *MnO* | *MgO* | *CaO* | *$Na_2O$* | *$K_2O$* | *$TiO_2$* | *LOI* | Total |
| P1-VI | Sediment | 26 | 74 | 68.07 | 13.21 | 5.31 | 0.09 | 0.72 | 1.44 | 1.65 | 4.51 | 0.69 | 3.78 | 95.69 |
| P1-V | Sediment | 45 | 55 | 67.24 | 14.55 | 4.95 | 0.10 | 0.82 | 1.34 | 1.77 | 4.49 | 0.67 | 2.86 | 96.46 |
| P1-IV | Sediment | 28 | 72 | 66.38 | 15.05 | 5.18 | 0.10 | 0.89 | 1.43 | 1.75 | 4.76 | 0.69 | 2.37 | 96.75 |
| P1-III | Sediment | 57 | 43 | 66.81 | 15.04 | 5.27 | 0.12 | 0.89 | 1.38 | 1.76 | 4.65 | 0.68 | 2.80 | 97.11 |
| P1-II | Sediment | 35 | 65 | 68.00 | 14.81 | 5.13 | 0.10 | 0.87 | 1.30 | 1.77 | 4.54 | 0.65 | 2.66 | 97.62 |
| P1-I | Sediment | 32 | 68 | 66.89 | 14.93 | 5.38 | 0.10 | 0.86 | 1.47 | 1.74 | 4.70 | 0.69 | 2.15 | 97.33 |
| P1-0 | Sediment | 17 | 83 | 67.17 | 14.81 | 5.23 | 0.10 | 0.85 | 1.48 | 1.78 | 4.63 | 0.68 | 2.07 | 97.18 |
| P1-VII | Skeleton | | | 65.12 | 16.68 | 5.08 | 0.09 | 1.07 | 0.75 | 1.97 | 6.11 | 0.67 | 2.04 | 97.54 |
| P1-VI | Skeleton | | | 68.02 | 14.46 | 4.91 | 0.12 | 0.87 | 1.56 | 1.45 | 4.66 | 0.72 | 2.05 | 97.17 |
| P1-V | Skeleton | | | 67.23 | 13.62 | 6.80 | 0.12 | 0.76 | 1.51 | 1.18 | 4.51 | 0.84 | 1.96 | 97.09 |
| P1-IV | Skeleton | | | 67.15 | 14.95 | 5.28 | 0.09 | 0.75 | 1.41 | 2.76 | 4.10 | 0.70 | 1.76 | 97.65 |
| P1-III | Skeleton | | | 68.38 | 14.70 | 4.31 | 0.11 | 0.79 | 1.43 | 2.00 | 4.46 | 0.63 | 1.92 | 97.25 |
| P1-II | Skeleton | | | 68.96 | 14.57 | 5.83 | 0.12 | 0.77 | 1.60 | 1.87 | 4.57 | 0.73 | 1.83 | 99.69 |
| P1-I | Skeleton | | | 68.16 | 14.38 | 4.59 | 0.08 | 0.85 | 1.05 | 1.88 | 4.61 | 0.64 | 1.97 | 96.70 |
| P1-0 | Skeleton | | | 64.50 | 15.21 | 6.54 | 0.11 | 1.01 | 1.40 | 1.48 | 5.15 | 0.77 | 2.14 | 96.61 |
| P2a-II | Sediment | 43 | 57 | 65.67 | 14.67 | 4.71 | 0.09 | 1.67 | 2.54 | 2.56 | 3.48 | 0.64 | 2.91 | 96.49 |
| P2a-I | Sediment | 64 | 36 | 71.01 | 12.57 | 4.77 | 0.09 | 1.63 | 3.30 | 2.45 | 2.40 | 0.76 | 1.57 | 99.56 |
| P2a-III | Skeleton | | | 70.63 | 13.51 | 3.94 | 0.08 | 1.03 | 2.25 | 2.93 | 3.31 | 0.44 | 1.55 | 98.40 |
| P2a-II | Skeleton | | | 65.23 | 15.24 | 4.49 | 0.10 | 1.45 | 2.03 | 2.27 | 4.54 | 0.64 | 2.13 | 96.37 |
| P2a-I | Skeleton | | | 70.30 | 13.73 | 3.70 | 0.07 | 1.05 | 1.87 | 2.24 | 4.04 | 0.47 | 1.72 | 97.80 |
| P2b-II | Sediment | 43 | 57 | 63.18 | 14.50 | 6.13 | 0.11 | 1.88 | 3.10 | 2.20 | 3.64 | 0.79 | 3.69 | 95.53 |
| P2b-I | Sediment | 36 | 64 | 67.98 | 12.90 | 4.63 | 0.08 | 1.56 | 2.94 | 2.43 | 2.67 | 0.70 | 2.14 | 96.42 |
| P2b-III | Skeleton | | | 66.90 | 13.92 | 5.59 | 0.09 | 1.36 | 2.93 | 1.79 | 4.35 | 0.70 | 1.81 | 97.63 |
| P2b-II | Skeleton | | | 68.23 | 14.33 | 4.54 | 0.08 | 1.17 | 2.08 | 2.09 | 4.21 | 0.64 | 1.95 | 97.84 |
| P2b-I | Skeleton | | | 80.26 | 8.36 | 2.59 | 0.04 | 1.00 | 0.88 | 0.76 | 3.00 | 0.35 | 1.32 | 97.49 |

| | Trace Elements (ppm) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample** | Sc | V | Cr | La | Nb | Pb | Zn | Ga | Th | Y | Nd | Mn | Ba | Ce | Zr | Rb | Sr |
| P1-VI | 11 | 47 | 15 | 44 | 18 | 39 | 44 | 13 | 12 | 32 | 29 | 569.9 | 621.3 | 79.1 | 335 | 132 | 144.8 |
| P1-V | 13 | 57 | 17 | 51 | 19 | 35 | 58 | 17 | 19 | 37 | 30 | 687.8 | 842.5 | 113.2 | 475.4 | 170 | 165.6 |
| P1-IV | 14 | 61 | 49 | 53 | 20 | 36 | 62 | 17 | 19 | 38 | 29 | 717.3 | 894.7 | 130.8 | 455.8 | 181.4 | 170.2 |
| P1-III | 15 | 59 | 17 | 61 | 20 | 36 | 60 | 17 | 20 | 38 | 41 | 698.1 | 869.1 | 121 | 458.2 | 176.4 | 168.1 |
| P1-II | 12 | 59 | 17 | 55 | 18 | 36 | 57 | 16 | 15 | 34 | 32 | 675.4 | 858.5 | 100.5 | 422.1 | 172 | 163.9 |
| P1-I | 13 | 60 | 15 | 54 | 20 | 36 | 63 | 17 | 18 | 39 | 34 | 732.2 | 866.7 | 127.4 | 508.1 | 176.4 | 173.8 |
| P1-0 | 14 | 59 | 20 | 45 | 20 | 37 | 61 | 17 | 20 | 39 | 38 | 741 | 858.5 | 163.1 | 430.8 | 176.7 | 173 |
| P1-VII | 14 | 39 | 32 | 23 | 17 | 24 | 53 | 16 | 21 | 30 | 16 | 514.3 | 798.7 | 57.7 | 218.9 | 186.4 | 53.3 |
| P1-VI | 14 | 59 | 28 | 36 | 21 | 41 | 60 | 17 | 17 | 36 | 18 | 720.5 | 869.3 | 78.9 | 387.5 | 177.8 | 197.4 |
| P1-V | 15 | 69 | 52 | 55 | 22 | 43 | 62 | 16 | 23 | 35 | 20 | 838.4 | 834.6 | 150.3 | 481.6 | 175.5 | 185.5 |
| P1-IV | 10 | 54 | 24 | 48 | 20 | 37 | 53 | 17 | 24 | 31 | 19 | 631.7 | 730.5 | 105.2 | 363 | 156.4 | 171.5 |
| P1-III | 12 | 49 | 20 | 48 | 19 | 38 | 53 | 16 | 19 | 37 | 25 | 643.1 | 818.7 | 91.7 | 366.1 | 167 | 184.7 |
| P1-II | 15 | 58 | 25 | 46 | 24 | 32 | 58 | 17 | 16 | 42 | 22 | 680.8 | 817.5 | 65.5 | 309.2 | 173.1 | 144.9 |
| P1-I | 13 | 58 | 19 | 49 | 22 | 30 | 59 | 16 | 18 | 48 | 32 | 592.6 | 829.2 | 163.7 | 381.7 | 175.5 | 117.2 |
| P1-0 | 14 | 74 | 25 | 71 | 20 | 35 | 70 | 18 | 28 | 35 | 33 | 804.6 | 936 | 135.5 | 310.4 | 205.4 | 148.9 |
| P2a-II | 12 | 65 | 53 | 37 | 13 | 29 | 58 | 16 | 12 | 26 | 25 | 617.8 | 761.4 | 66.9 | 251.1 | 120.2 | 250.6 |
| P2a-I | 15 | 74 | 66 | 45 | 15 | 28 | 46 | 13 | 9.4 | 34 | 30 | 598.2 | 599 | 66.6 | 466.2 | 74.4 | 317.2 |
| P2a-III | 11 | 48 | 32 | 42 | 10 | 37 | 54 | 15 | 8.1 | 22 | 25 | 559.3 | 686 | 56.5 | 164.4 | 111.1 | 252 |
| P2a-II | 15 | 58 | 34 | 42 | 14 | 28 | 63 | 17 | 11 | 25 | 20 | 536.9 | 929.6 | 54.2 | 248.8 | 151.5 | 196.6 |
| P2a-I | 12 | 42 | 34 | 48 | 11 | 30 | 46 | 15 | 8.7 | 23 | 31 | 482.7 | 802.6 | 57.9 | 246.1 | 130.3 | 199.7 |
| P2b-II | 13 | 70 | 60 | 47 | 14 | 29 | 50 | 15 | 12 | 30 | 27 | 598.8 | 642.9 | 80 | 367.8 | 88.6 | 277.4 |
| P2b-I | 13 | 68 | 59 | 40 | 15 | 28 | 50 | 14 | 10 | 33 | 32 | 609.6 | 636 | 75.4 | 413.1 | 86.5 | 287.6 |
| P2b-III | 12 | 50 | 30 | 48 | 15 | 33 | 50 | 14 | 12 | 29 | 30 | 543.9 | 752.3 | 67.7 | 236 | 109.8 | 275.2 |
| P2b-II | 13 | 60 | 37 | 45 | 14 | 31 | 53 | 16 | 15 | 25 | 27 | 588.1 | 888.1 | 66.9 | 316.6 | 131.8 | 243.9 |
| P2b-I | 9.9 | 32 | 18 | 20 | 6.9 | 18 | 36 | 8.8 | 6.8 | 14 | 13 | 305.5 | 648.7 | 29.7 | 122.5 | 96.9 | 69.5 |

**Tab. 4** Composition of minerals (%) from fine matrix and skeleton samples.

| Mineral Composition (%) | | | | | | |
|---|---|---|---|---|---|---|
| *Sample* | *Type* | *Quartz* | *Mica* | *Plagioclase* | *Amphibole* | *Kaolinite/Chlorite* |
| P1-VI | Sediment | 67 | 21 | 12 | | |
| P1-V | Sediment | 48 | 34 | 17 | | |
| P1-IV | Sediment | 41 | 46 | 13 | | |
| P1-III | Sediment | 53 | 37 | 9 | | |
| P1-II | Sediment | 47 | 36 | 17 | | |
| P1-I | Sediment | 49 | 34 | 17 | | |
| P1-0 | Sediment | 51 | 34 | 15 | | |
| P1-VII | Skeleton | 48 | 29 | 23 | | |
| P1-VI | Skeleton | 49 | 37 | 14 | | |
| P1-V | Skeleton | 53 | 37 | 10 | | |
| P1-IV | Skeleton | 47 | 22 | 30 | | |
| P1-III | Skeleton | 42 | 38 | 20 | | |
| P1-II | Skeleton | 39 | 38 | 23 | | |
| P1-I | Skeleton | 56 | 27 | 17 | | |
| P1-0 | Skeleton | 34 | 46 | 20 | | |
| P2a-II | Sediment | 51 | 23 | 25 | 1 | 1 |
| P2a-I | Sediment | 66 | 9 | 22 | 2 | 1 |
| P2a-III | Skeleton | 58 | 13 | 28 | | |
| P2a-II | Skeleton | 43 | 30 | 27 | | |
| P2a-I | Skeleton | 54 | 23 | 23 | | |
| P2b-II | Sediment | 57 | 13 | 27 | 1 | 1 |
| P2b-I | Sediment | 65 | 14 | 19 | 1 | 1 |
| P2b-III | Skeleton | 60 | 21 | 19 | | |
| P2b-II | Skeleton | 51 | 28 | 21 | | |
| P2b-I | Skeleton | 80 | 15 | 5 | | |

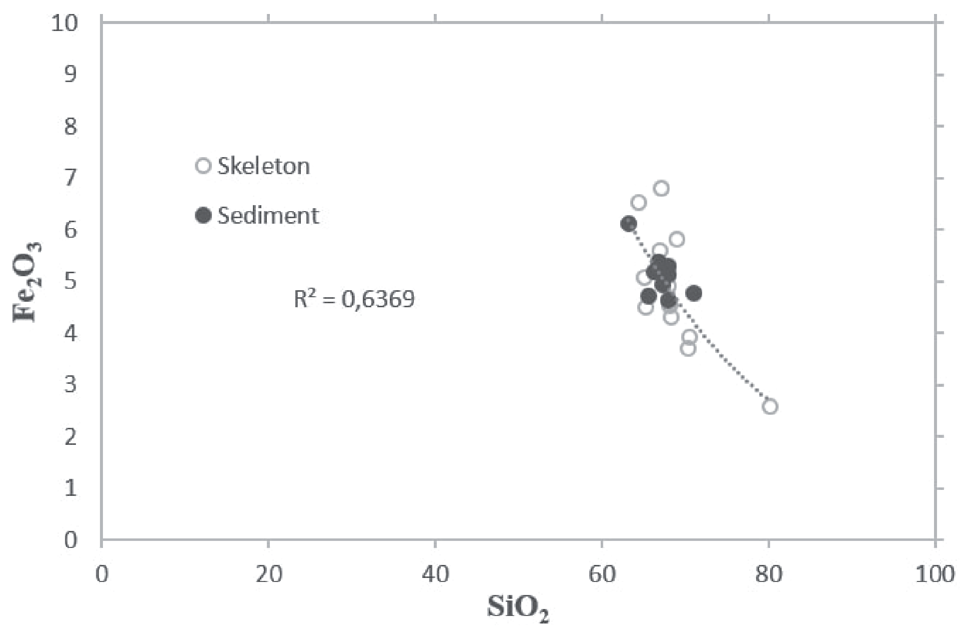


**Fig. 9** Statistical relationship between silica and iron in all samples (fine matrix and skeleton). Gradual quartz leaching in conjunction with iron enrichment seems to be an important chemical weathering aspect.

noteworthy, displaying the most weathered rock sample at Blåhø, respectively Rundhø. This indicates more severe exposure to weathering than other horizons. Several authors (e.g. Lautridou and Seppälä 1986; Whalley et al. 2004) have provided information about very low physical weathering intensities under present climate. As such, recent weathering intensity seems to be too weak to produce fines (< 0.063 mm) and too slow to reach the weathering states of our profiles (Whalley et al. 2004). Further, our clay/silt ratios indicate a low chemical weathering (Goodfellow 2012). Accepting the findings of Rea et al. (1996), a post-LGM formation of our profiles with a depth of more than one meter must be questioned. Our grain sizes draw a contrary picture of the expected little soil development in this environment (Darmody and Thorn 1997; Darmody et al. 2000). The relatively high quantity of fine matrix can be explained by sufficient time for production through repeated glacial-interglacial cycles (Goodfellow et al. 2009). The presence of soil horizons, relatively high amount of fine matrix and lichen cover indicate that periglacial surface processes are largely inactive (Goodfellow et al. 2009), especially at P1. It could seem surprising how fine material beneath the blockfield is not largely eroded. A gently dipped autochthonous blockfield protects for the underlying soil matrix and partly hinders erosional processes (Boelhouwers 2004), other authors (see Goodfellow 2007) show that blockfields inherit pre-Holocene material. At road cuts around Rundhø till is visible about three meters below the autochthonous and sorted surface rocks. This shows the past and relict glacial influence. Interpretations of Rundhø pits is far from straightforward as the slope angle leads to disturbance within the soil. The presence of blockstreams indicates at least relict permafrost influence (Goldthwait 1976). This is sustained by Farbrot et al. (2011) who detected seasonal permafrost in a depth down to ~7.5 m and permanent permafrost at least above 1560 m a.s.l. The observed cryogenic influence (cryoturbation soil pocket) at P1-V support the assumption that thermal conditions at the study site allow cryogenic processes to act. These can only act in this way, however, when the area was not ice covered. Based on this consideration our profiles seem to inherit a complex and long history probably extending beyond the Holocene.

### 5.2 Chronology and considerations about cold-based ice

South-central Norway's landscape history is largely influenced by glacial activity, thick till deposits were detected in and around Gudbrandsdalen (Bergersen and Garnes 1981). During the last major Quaternary glaciation ice flow directions changed, Bergersen and Garnes (1983) postulated four main phases of glaciation. During the initial glaciation phase, Ottadalen and Gudbrandsdalen were influenced by south-westerly ice flow from Jotunheimen which later changed to north-western flow direction during an early phase of the LGM where most till was deposited and a north-eastern flow during the YD. With the ice flow, also the ice divide migrated during the initial phase from north east of the study site, 150 km to the south west, crossing Blåhø, offering the possibility of a thin ice cover. Summits were ice free very early during deglaciation (see Bergersen and Garnes 1983, Figure 34).

The presence of relict landforms in Scandinavia is often explained by the presence of cold-based ice (e.g. Kleman 1994). Sollid and Sørbel (1994) identify former cold-based ice coverage by meltwater channels cutting through blockfields and drumlinoid landforms existing independently to topography indicating a thick ice sheet. Further, Sollid and Sørbel (1994) suggest a warm-based glacier becoming cold-based. This would indicate the incorporation of non-local material transported subglacially. However, we neither detected meltwater channels cutting through blockfields, nor non-local lithology. The consistent lower blockfield boundary in the region is often interpreted as an englacial boundary between cold and warm-based ice but this is unlikely as the thermal boundary should not be parallel to the ice surface (Nesje et al. 1987; Nesje and Dahl 1990).

In contrast to the postulated preservation ability of cold-based ice, it can act as an erosive agent as shown at a thin valley glaciers (Echelmeyer and Zhongxiang 1987; Astakhov et al. 1996). This is supported by Steer et al. (2012), who claim that not only fjords but also high-elevation low-relief surfaces contributed to erosion. Therefore, complete landform preservation without disturbing the surface setting cannot be ensured. Southern Scandinavia was uplifted 1000–1500 m in the Paleogene and 1000 m in the Neogene (Riis 1996). Subsequently, Neogene erosion removed 800–1000 m near the coast. Surface lowering probably more than 100 meters within the Quaternary has to be considered (Steer et al. 2012). The present uplift is estimated 2–3 mm/yr (Fjeldskaar et al. 2000).

The Dye-3 ice core data from Greenland confirm lower annual precipitation during the LGM than during the Holocene for southern Norway (Paterson and Hammer 1987). Almost permanent ice masses in the Norwegian Sea and North Atlantic, moving Atlantic cyclones southward effectively reduced the primary origin of precipitation (Nesje et al. 1988). The little precipitation nowadays is comparable to the precipitation during glacials, supporting the emergence of only thin ice sheets (Dahl et al. 2004). Mangerud (2004) point out that sufficient precipitation is an important factor in the build-up of cold-based ice. We argue that the combination of little precipitation and its key role for cold-based ice build-up, prevented the development of a thick ice sheet in south-central Norway in the Late Weichselian.

Terrestrial cosmogenic nuclide data presented by Goehring et al. (2008) are the main argument for LGM cold-based ice on Blåhø. Their exposure age (25.1 ± 1.8 $^{10}$Be ka) from the summit is based on a single erratic and do not take into account erosion or snow shielding, leading to age underestimation (Lal 1991; Gosse and Phillips 2001; Stroeven et al. 2016). As erosion was neglected exposure ages can only yield minimum ages (Dunai 2010). The accuracy of cosmogenic nuclide ages is yet to be improved, the discrepancies in the production of $^{10}$Be is around 40% (Gosse and Phillips 2001). In agreement with Ballantyne (1998) we thus state that erratics could have derived from earlier glaciations of unknown age. Moreover, erratic exposure ages are interpreted equivalent to deglaciation (Stroeven et al. 2006), based on the unconfirmed assumption that Blåhø was glaciated. Other expected evidence for cold-based ice refer to the existence of lateral channels, till and scoured bedrock (Sugden and Watts 1977; Dyke 1993). In contrary, all characteristics are absent in the summit area. Bringing together the mentioned findings, in situ cold-based ice formation on Blåhø during the LGM is unlikely. A warm-based ice sheet, instead, which might have frozen to the substratum, becoming cold-based would have demanded the presence of glacially transported material in the profiles which we did not detect. Therefore, precluding cold and warm-based ice, our results cannot exclude the nunatak theory during the LGM, despite the largely accepted cold-based ice theory in Fennoscandia.

### 5.3 Soil profile chronology

Beside the above mentioned considerations our soil horizons seem to inherit a long and complex history. We applied the growth rate from Matthews (2005), for the mean of the five largest lichens. Ages of 462 yr (P1), respectively 463 yr (P2) are estimated (Table 5). The range of error is complicated to determine as we are applying an existing growth rate with an estimated overall error of 62 ± yr (Matthews 2005), and our measurements bear a 95% confidence interval in years of 462 ± 24.9 yr (P1) and 463 ± 11.6 yr (P2). As local micro-conditions are more important than climate, a slower growth rate (Trenbirth and Matthews 2010) should be considered; in our case due to the low precipitation sums in the study area. It has to be noted that there are many uncertainties involved in lichenometry, e.g. mortality due to snow, the radial growth of lichens, their growth behavior in general, and the influence of competition (e.g. Osborn et al. 2015; Armstrong 2016). We used the successful applied growth rate and the assumptions made by Matthews (2005), being aware that other studies use different assumptions (see Osborn et al. 2015).

**Tab. 5** Lichenometric dating, ages calculated with growth rate of 0.45 mm/yr (Matthews 2005)

| Five largest lichens | P1 | P2 |
|---|---|---|
| Mean (mm) | 208.0 | 208.2 |
| Median (mm) | 233 | 210 |
| Standard deviation | 44.5 | 20.86 |
| Standard error of the mean | 19.9 | 9.32 |
| Confidence interval of the mean (95%) | 55.3 | 25.9 |
| Estimated age (yr) | 462.0 | 463.0 |

Our histograms indicate a complex colonization history, and the high number of small lichens is noteworthy. The skewed nature of the lichen distribution could reflect delayed or different phases of colonization (Roberts et al. 2010), stressing the longevity of the population. The measured diameters larger than 140 mm indicate to predate the Little Ice Age (LIA) (Matthews and Shakesby 1984). As our largest individuals are supposed to be relatively old, the amount of smaller specimen show that the lichen community is dynamic, reproducing and that our estimated ages are not unrealistic. Ages of P1 are considered to be more reliable due to flat topography and surface arrangement. Lichens at northern exposure from P1 might be older than from P2, experiencing longer lying snow and less insolation, lichens at P1 need more time to reach the same thalli diameter (Griffey 1977). The range lichenometric dating is sufficient for our study to determine, if the surface was disturbed by the LIA. Due to Osborn et al. (2015), this is possible by using large Rhizocarpon thalli. The Neoglacial peak during the LIA which was observed at many Norwegian glaciers (Nesje 2009) did not glacially influence our study site. There is no indication that the blockfield influenced by glacial activity post-dating the rock shattering. The surface is dominated by angular rocks without structural orientation from glacial influence. Cook-Talbot (1991) shows that surface clasts surviving the LIA are stable for several hundred years. The most severe climate detoriation predating the LIA is the Younger Dryas (YD) which might have altered the landscape. Follestad (2007) mapped YD moraines up to 1400–1500 m a.s.l. approximately 50 km north of our study site, which can be interpreted as the YD ice surface. This observation and including the lack of glacial erosion, we assume that Blåhø was not affected by the YD. Goehring et al. (2008) investigated erratic boulders on Blåhø from 1086 and 1182 m a.s.l. representing quick ice sheet lowering from 15.0 to 11.7 ka., supporting no ice cover at the summit during YD. Hence, we consider minimum blockfield surface stability since at least 12.5 kyr.

Consequently, P1-VI is exposed to the surface since at least 12.5 kyr, this is supported by the high proportion of sand inducing continued aeolian processes removing smaller fractions and high LOI content which incorporates organic content from the climate amelioration ~7.5 to 6.4–6.1 kyr (Paus et al. 2011). The properties of P1-V concerning the weathering indices, the leaching of trace elements, the high silt volumes, and its dark upper part appear to reflect the Eemian interstadial (MIS 5e, 130–115 kyr). MIS 5e is the only eligible period in terms of temperature and duration which might have caused the profile characteristics. The periglacial involution reflected in the upper part of P1-V might have taken place during the climatic cooling (French 2007) after the Eemian towards MIS 2 (LGM). We thus argue that the lower part of P1-V marks the transition between MIS 6 to MIS 5 with slowly increasing temperatures indicated by higher organic content in the profile. Probably P1-IV represents the periods from MIS 9 to MIS 6 (337–130 kyr) with continuously cold temperatures and only minor periods of climatic amelioration. This assumption is sustained by lighter color, lower organic content and lower abundance of sand. The low amount of sand might evolve from slow chemical weathering during long-term cold conditions causing relatively fresh CIA and WIP values. The dark layer of the upper part of P1-III and P1-II must have developed in earlier interglacials. Further exploration of the age of the blockfield by cosmogenic nuclides exposure age dating is in progress.

Concluding, all our site related information point to the fact that blockfields in south-central Norway were not generally covered by cold-based ice during recent glaciations. We argue that the prerequisites for build-up a cold-based ice cap were not given in the area during recent glaciations. Furthermore, the profile properties indicate a long chemical weathering history under changing environmental conditions. Therefore, cold-based ice coverage cannot conclusively be excluded, but appears to be unlikely.

## Acknowledgements

We are thankful to Simone Ackermann who provided expertise in field and lab. Furthermore, we thank the Svare family for support. We are also grateful to the Steinmann-Institute, University of Bonn for the support in the laboratory, special thanks to Dr. Sven-Oliver Franz. Thanks to Camilla Kurth for assistance and advices in our laboratory. We thank the Friedrich-Ebert-Stiftung for their financial support. We also thank two reviewers for improving the paper significantly.

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# DIVERSIFICATION TRENDS IN MOLDOVAN INTERNATIONAL MIGRATION: EVIDENCE FROM CZECHIA AND ITALY

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**ABSTRACT**

This contribution advances knowledge of contemporary Moldovan migration and is the first comparative description of the situation of Moldovans in Czechia and Italy. Our specific objective is to review evidence about how the concept of the migration-development nexus applies to the Moldovan situation. In the absence of comparable primary data on Moldovan migration our research design uses mixed methods and triangulates data from Moldova and across the main destinations for Moldovan migration, including Italy and Czechia. In addition to confirming prior research on the significance of remittances to the Moldovan economy since 1991, we report three additional findings. First, Moldovan migrants, particularly women who may work as domestic workers are often invisible and undercounted. Second, Moldovan migration is rapidly diversifying, with new destinations, selectivities, and forms and modes of mobility. Third, the global economic recession of 2008 had different implications for Moldovan migration patterns to and from Czechia and Italy. We conclude with a specific call for research that extends the migration-development nexus by examining social remittances and the mobility and labour strategies of Moldovan family reunifiers. The paper also argues for availability of robust data that would allow comparative analysis of international migration and could better support evidence-based debates about migration.

**Keywords:** international migration; Moldovan migrants; Moldova; Czechia; Italy; labour markets

Received 31 December 2016; Accepted 18 October 2017; Published online 24 November 2017

## 1. Introduction and main goals

Approximately 250 million international migrants – 3.4% of the world's population – had been living outside their country of birth for more than 1 year in 2014 (World Bank 2016a). As most migrants move in the direction of economic opportunity the "migration-development nexus" has emerged as an influential explanation of, and policy heuristic for international migration (Faist 2004; King et al. 2013). Recent work contends that migration issues have a pendulum-like character, going back and forth from more pessimistic to more optimistic treatments as de Haas (2010, 2012). For example, around the beginning of the new millennium, the overall assessment was often in positive tone, with financial remittances offering a win-win-win for origins, destinations, and migrants through processes of brain gain, positive role of diasporas, and circulation migration (GCIM 2005). However, securitization, global economic recession, persisting discrimination against migrants, the impact of circulation upon integration, and a wider breakdown of migrant social and family relations have suggested the pendulum may be swinging back (de Haas 2007b; Triandafyllidou 2013). Set within our broad goal of advancing an understanding of contemporary international migration, the specific objective of this paper is to review evidence on how the concept of the migration-development nexus applies to the particular situation of Moldovan migration.

The Moldovan migration system is a compelling one to study. Moldova is deeply affected by migration and has received financial remittances since independence (Ruggiero 2005; Pinger 2010). Financial remittances of Moldovan migrants represent a very important source of income (Piracha, Saraogi 2011; Siegel, Lücke 2013). As a result, Moldovans move globally, with new streams touching new origins and reception contexts, including southern Europe and Central and Eastern Europe (CEE). However, continuing research reveals complicated negative externalities. This includes the issue of children left behind (Salah 2008; Gassmann et al. 2013) and the transformation of social roles in a transnational context. This draws attention to the social dynamics within the Moldovan diaspora and to the interactions between immigrants and the host society (Babenco, Zago 2008). Besides the role of the Orthodox Church as one of the main actors in constituting the individual and collective identity of Moldovans abroad, researchers highlighted the crucial activity of cultural associations and the professional and non-professional folkloric groups (Piovesan 2012). Moldovan migration is also driven by changing international

https://doi.org/10.14712/23361980.2017.19
Drbohlav, D. – Bailey, A. J. – Čermák, Z. – Čermáková, D. – Lozovanu, D. – Masná, E. – Pavelková, L. – Seidlová, M. – Stojanov, R. – Valenta, O. – Vietti, F. (2017): Diversification trends in Moldovan international migration: evidence from Czechia and Italy
AUC Geographica, 52, No. 2, pp. 237–248

and national policy regulations, particularly since the global economic recession and rising security concerns.

To study how Moldovan migration is driven by these multilayered economic, political, and social processes we compare one national group (Moldovans) across two destinations rather than comparing different national groups in one destination (for example Marchetti and Venturini's analysis of Moldovans and Ukrainians in Italy, 2014). This helps explore how the different migrant practices, reception contexts, and policies of the migration-development nexus affect Moldovan migration.

To begin to fill this research gap we use a comparative design to focus on Moldovans in a long established destination where migration amnesties affect labour markets (Italy) and in a more recent destination (Czechia) with more reactionary migration regulations. Qualitative research on Moldovans in Italy explores the female care-chain that links Moldovan women to the Italian families where they work and at the same time to their own families waiting for them at home in Moldova (Mazzacurati 2005; Boccagni 2009). These studies analyse the cultural, social and economic behaviour of migrants in terms of transnational practices, discussing issues related to the different household strategies, the wellbeing of "left-behind" people (especially children and grandparents), the changes in the use of the money sent by migrants, the transformations in contemporary Moldovan society driven by emigrants' social remittances. Czechia is the most migratory attractive country (in absolute terms) of all the CEE countries and, as a member of the European Union (EU), hosts about half a million legally resident foreigners including Moldovans who began arriving after 1989 (ČSÚ 2015; Drbohlav et al. 2010).

The paper makes two broad contributions. First, we are the first to assemble and contribute new knowledge on Moldovan migration to Czechia and Italy. To date in Czechia, there is no study focusing on Moldovan migrants and their migratory and integration patterns. Thus, this contribution is, to some extent, filling a gap that exists in this area of research by using a unique database (e.g. on foreigners' employment in Czechia). Second, we raise a series of research questions that may extend the migration-development nexus and guide policy development.

The rest of the paper is structured in three parts. We introduce the main ways in which Moldovan international migration has diversified since independence in 1991. We then describe and compare the experiences of Moldovans in Italy and Czechia, with an emphasis on labour market, historical developments, and geographic diversities. The third section discusses how the comparison extends the concept of the migration-development nexus. The final section summarises our general contribution to understanding Moldovan migration and concludes with a call for more research on social remittances and for robust data.

## 2. Diversification of post 1991 international migration of Moldovans

In common with many contemporary territories, the seemingly neat cartographic boundaries of today's Moldova obscure complicated geopolitical and cultural traditions. That is, the Republic of Moldova includes the eastern part of historical Moldova, which was in the last two centuries successively administered by the Russian Empire (1812–1918), Romania (1918–1940/1941–1944) and the USSR (1944–1991). While Moldova has been an independent state since 1991, part of what appears under government jurisdiction is not under the control of the authorities, instead constituting a secessionist "Dniester Moldovan Republic" in the eastern part of the country.

These recent and multi-layered transformations are accompanied by equally complex and historically variable migration systems. Here, we focus on the significant changes that are unfolding in the geographies of international migration since 1991. The economic collapse that followed the political one led to the loss of many jobs in industry and agriculture, wages that were insufficient to meet basic needs, and a range of social problems. While for the years 1989–1991 emigration balanced immigration, 1992 marked a turning point, and since then emigration has exceeded immigration. In 1994 the number of emigrants was already double that of immigrants (Mosneaga 1999: 70–71).

Since independence international migration has been overwhelmingly influenced by Moldova's socioeconomic problems. Most migrants are classified as labour migrants. Of this population, 56% are males and 44% females. Their pattern of destinations has undergone significant transformations over the past twenty five years (de Zwager, Sintov 2014). Preceding independence, the regions of the former Soviet Union, especially those with oil related employment (including Khanty-Mansiysk and Yamalo-Nenets), were dominant destinations. Recently, emigration to Europe has grown fast, particularly to the Mediterranean region, where Italy and Portugal emerged as the most important destinations, followed by Spain, Greece and Cyprus, at least until early 2008. Ireland became attractive during the economic boom and attracted migrants in 2002–2009. France, Belgium and Germany have become more attractive in the last decade and the Scandinavian countries have also recorded a gradual growth of Moldovan migrants in recent years. Among post-communist countries, Czechia is the most attractive and has the largest concentration of Moldovans, followed by Poland and Slovenia. Seasonal migration, defined as migration for less than 9 months per year, involves an estimated 109,000 Moldovans or represents 3.3% of the total population. 81% of seasonal workers migrate to Russia, with Italy a distant second with 7%. Most recently, there is an increase in the secondary migration of Moldovans to the United Kingdom (UK) from countries of the EU where they were previously employed, such as Romania, Portugal, Spain, Greece or Italy. Indeed, migration geographies now extend beyond Europe. New destinations include the United Arab Emirates (UAE), Qatar and Kuwait, South Korea and Australia. In summary, recent data suggests that 56% (or 206,000) of Moldovan labour migrants are in Russia, 22% (or 81,000) in Italy, and between 2% and 3% (or 8,000 to 10,000) in each of France, Turkey and Portugal (de Zwager, Sintov 2014).

The migration system is also diversifying to include a range of forms of mobility. For example, 18,400 Moldovans are studying abroad, and 18,700 people have migrated for the purpose of family reunification. Return migration is also increasing. Between 1992 and 2013, 44,000 international migrants, or 1.3% of the total Moldovan population, returned to Moldova, affecting 3.2% of Moldovan households. Of this number, 54.5% returned in 2010–2013; 49% returned from Russia, 15% from Italy and 12% from Israel (de Zwager, Sintov 2014).

Taken together, these changes mean that, in Moldovan society, up to one in three persons are directly impacted by some form of mobility: 38.6% of Moldovan households had one or more persons involved in international migration and/or geographical mobility (internal mobility), 29.4% of households had one, more or all members involved in international migration, either long-term or seasonal. 12.4% of the total population is in long-term international migration, including 11% classified as labour migrants.

However, while migration touches many Moldovans the precise patterns of emigration vary across the different districts and localities in Moldova. Thus, most people who have emigrated to Italy, Portugal, Spain, France, Britain and other EU countries come from central districts of Moldova, and are mostly ethnic Moldovans/Romanians. Moldovans from northern, eastern and southern Moldova go mostly to Russia, whereas the majority of Moldovan migrants from southern Moldova, particularly from Gagauzia, go to Turkey. Territorial correlations can be found also at the level of settlements. For example, many migrants in Ireland are from the town of Durleşti (Chisinau), in the UK from the villages of Costesti (Ialoveni) and Colibași (Cahul), in France from Corjeuti and Caracuşenii Vechi (Briceni). In Italy and Portugal they are from several localities from Hincesti, Straseni, Nisporeni, Anenii Noi districts, etc.

These trends in the diversification of Moldovan migration point to a combination of familiar and unique processes. A large part of migration is economically motivated. Moldova is one of the poorest countries in Europe. GDP per capita (purchasing power parity in USD) was 4,893 – 128th out of 183 assessed countries of the world (World Bank 2016b). Similarly, Moldova has a poor position in regard to the more complex human development index (HDI) – it stood at 0.693 in 2014, thus ranking Moldova in 107th position out of 185 countries of the world (UNDP 2015). After 1990, the Moldovan economy went through major structural transformation. The share of agricultural production on GDP dropped from 42% to 10% between 1989 and 2012, while high employment in the sector was not greatly changed – standing at 25% of the economically active population in 2012 (Ghedrovici 2014).

This punishing socioeconomic context means that many Moldovans turned to migration so they could send financial remittances to provide sufficient earnings to support family. Indeed, these financial remittances[1] are important in the aggregate to the Moldovan economy. From the economic perspective, for many European and Central Asian (ECA) countries, remittances are the second most important source of external finance after foreign direct investment (FDI). In Moldova, remittances bring in foreign exchange equivalent to almost half of export earnings. However, official remittances figures tend to undercount the actual flows by the amounts sent through informal networks in most instances (Mansoor, Quillin 2007). Moldova has the highest ratio of remittances to GDP income of all European countries (26% – World Bank 2016c) and in fact is among the economies with the highest ratio of this indicator in the world.

The significance of remitting helps explain why some migrants are drawn to prevailing high-wage regions of Russia as well as the EU countries, the USA, Canada, Australia, South Korea, UAE, Qatar, and Turkey. The institutional importance of remitting to the economy also helps explain why Moldovan migration has been increasingly subject to policies enacted in the name of the migration-development nexus. This includes a growing range of visa, entrance, and citizenship policies that, generally, affect labour market accessibility and opportunities to remit (GCIM 2005). Thus, visa-free access to Russia, Ukraine, Belarus and Kazakhstan has accelerated migration to these countries. While Moldova is not a member of the EU it has been increasingly affected by European policies that have sought to manage the migration-development nexus as part of a broader geopolitical, socio-economic, and ideological project (Carrera 2007). In 2003, Moldova became part of the European Neighbourhood Policy (ENP) aimed to bring democracy, the rule of law, a respect for human rights, and social cohesion to Europe's eastern and southern neighbours (European Commission 2015). As an ex-Soviet republic Moldova is also a member, since 2009, of Europe's Eastern Partnership (EaP), a forum for discussion of mutual interests in trade and political development. These general high level processes and dialogues impact Moldovan migration because they tend to carry Europe's increasingly connected foreign policy agendas and border management strategies. For example, Europe's Global Approach to Migration (GAM) sought to manage migration in ways that could be of use to Member States and, through remittances, for origin countries (GCIM 2005). In Moldova, this included the signing of a Mobility Partnership which aimed to provide

1 Simply defined as mainly money, but also payment in kind, wired/transferred or brought by migrants back home, mainly for their family members – see World Bank (2016c).

economic remittances, benefit the economy through the transfer back of skills, and secure foreign investments. Under GAM, Moldovan border control and migration management were aligned with European protocols, with FRONTEX assuming a greater role in border control and readmission agreements proposed to increase the volume of short-term and temporary migration between Moldova and European Member States. A series of geopolitical and economic events – including instability in the Middle East and North Africa, and global recession – transformed European policy (Van Houtum 2010). For Moldova this ended the ENP Action Plan in June 2014 and replaced it with an Association Agreement between the EU and Moldova. This includes the Deep and Comprehensive Free Trade Agreement (AA/DCFTA) and affords Moldovans with biometric passports the opportunity to travel, visa-free, to Schengen countries. In 2014, 340,000 Moldovans had used such facilities (European Commission 2015).

These changing policies have greatly increased the range of strategies that are available to, and are being used by Moldovans seeking mobility. Here we briefly introduce seven modes which variously extend the range and flexibility of opportunity for Moldovan migrants wishing to work to remit. First, emigration can be enabled by obtaining a pre-departure employment contract. This was originally important in states such as Israel, Poland, and the UAE, but now extends to work in the UK, Ireland, Germany, and Canada, although primarily on the basis of EU citizenship. Second, Moldovans leave with short-term visas enabling entry to the EU, the USA or Israel. After the expiry of their visa, some seek to remain as undocumented migrants in the country where they work. This strategy appears more important for the period until the abolition of the Schengen visa regime for Moldovan citizens in 2014. Third, Moldovans migrate based on specific education, working holiday, and other travel programs. This includes student visas, and may carry the possibility of post-education employment in the destination. Fourth, departures have been organized outside the above protocols (“illegally”) by smugglers and traffickers, especially in the years 1994–2004. Fifth, Moldovans leave with false identity documents, particularly those issued from Lithuania, Latvia, Romania, and Bulgaria. The destination was often the UK, Ireland, Italy, France or Spain. Sixth, Moldovans depart having first legally obtained citizenship of Romania, Bulgaria, Portugal or, increasingly, other European countries. This strategy started in 1996 and has accelerated since 2010. The advantages include being able to work freely in EU countries and being able to obtain rights in other states as well. Seventh, Moldovans obtain legal status while overseas, and may return and subsequently circulate. This includes those who lived in Canada (province of Quebec), Israel (Jewish ethnicity), Germany (German by blood line), Russia (via a program for returning compatriots), and the USA (via a green card). Other Moldovans have obtained legal status overseas through family reunification.

We also argue that while socio-economic conditions and changing policies underpin diverse mobility strategies, social and cultural factors enable and constrain the exact patterns of migration. First, as is evident in the choice of priority regions for those leaving Moldova, language heritage matters. Moldovans are generally bilingual, speaking a Romance language (Romanian) and a Slavic one (Russian). Migration to Russia and other countries with Slavic languages (such as Czechia) is strongly influenced by this, while the Romanian language opens easier access to Italy, Spain, Portugal and France.

Second, while many Moldovans do migrate to improve themselves, widespread poverty in Moldova means that family needs are as important and sometimes more important than strictly individual aspirations. This means that families and kin networks play a strong role in influencing the direction, timing, and consequences of migration strategies, with ongoing implications for the migration system. For example, because many migrants (men and women) often have children or parents who remain in Moldova, their absence has a major influence on their relatives, communities, and social relations. This includes the issue of “abandoned children” in Moldova: “The number of children left behind is high: more than 100,000 children, according to a 2012 UNICEF report. In 2011, one out of every five children in Moldova had a parent living abroad, while 10 percent had both parents abroad” (Yanovich 2015). With rapidly changing social relations, including the feminization of migration from Moldova (Vanore, Siegel 2015), institutions including the Orthodox Church more readily speak out and intervene in migration issues, further complicating a diversifying migration system.

## 3. Moldovan migrants in Italy and Czechia

This section further investigates the diversification of Moldovan international migration by focusing on the experiences of migrants in Italy and Czechia, with an emphasis on historical development, geographic organization, and labour market structure. We start by presenting the findings for the longer established and larger community in Italy and then compare this with Czechia. In both cases, we use a combination of established “official” sources and secondary sources, including our own experience of working in these locations. Triangulating across different sources has two advantages. First, statistical data on international migration are subject to systematic and gradual development, and are often far from being comprehensive. In the case of Czechia there is a paucity of relevant data on numbers, flows, types, motives, or preferences of international migrants[2]. For example, the data on employment of Moldovans (and all other foreign citizens) in Czechia is not available for 2012 and 2013 due to a collapse of the

2 Data on economic activities and residences of foreign citizens in Czechia are collected using different methodologies that do not permit direct cross comparison (see Drbohlav, Valenta 2014).

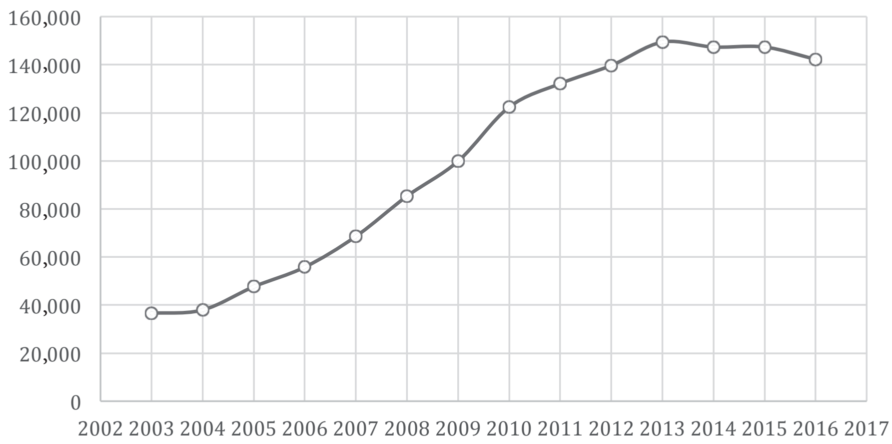

**Fig. 1** Moldovan migrants in Italy by regions and gender, 2015. Source: ISTAT (2016).

system of data collection and processing at the Ministry of Labour and Social Affairs in early 2012. Second, many Moldovans migrate as Romanians due to historic and linguistic connections and cultural and ethnic affinities, and the reality that Moldovans who have a Romanian passport and are registered as Romanian citizens in the EU have unrestricted access to the EU labour market.

### 3.1 Italy

Italy transitioned from a country of emigration to one of immigration after the 1990s as a significant number of immigrants, especially from the Balkans and the Mediterranean area arrived. Official statistics suggest that Moldovans were part of this shift, at first comprising a small and indeed invisible group of 7,000 people i.e., about 0.5% of the total of all foreign residents (ISTAT 2002). While quantitative and census data initially undercounted the community, ethnographic and qualitative research began to describe, particularly in some abandoned areas of the suburbs of the large cities, the appearance of buses going back and forth between Italy and the countries of Eastern Europe. Here, every week, Moldovan migrants who lived in Turin, Padua or Bologna came to send packages, gifts, money, letters and photographs to friends and relatives who remained in their country of origin. Thus, in the midst of washing machines, microwave ovens, packs of pasta and bottles of perfume, these parking spots become the starting point of a transnational story that continues to transform both Moldova and Italy (Vietti 2012).

Crucially, the 2002 *sanatoria* (regularization of undocumented immigrants) itself linked to the so-called "Bossi-Fini Act" led to a swift increase in the visibility of CEE communities. Women migrants were a key group to be recognized, of whom many had been employed as domestic workers or care assistants to elderly Italians. Italian society thus discovered the binomial *badanti moldave* as "Moldovan care-givers" became visible, both in




**Graph 1** Moldovans in Italy, 2003–2016. Source: ISTAT (2016).

the domestic space and the public imaginary and politics of the nation (Vietti 2010) – see Figure 1.

The *sanatoria* also prompted Moldovans to legalize their migration status in 2002. By the end of 2004 there were 36,000 recorded Moldovans, comprising one of the twenty largest foreign groups living in Italy. The population passed the symbolical threshold of 100,000 in 2009 and reached a peak of 149,000 people in 2013. After steady growth, the most recent data show a slight decrease, perhaps due to the global recession and economic crises that hit Italy after 2008. By 2016 there are around 142,000 Moldovans, or 2.8% of the total foreign population, forming the 8th largest immigrant group living in the country (IDOS 2016) – see Graph 1.

The Moldovan population in Italy is predominantly made up of women (66%). It is also distinctive in that the average age is considerably higher than for immigrants of other origins: 23% are over 50 years old (for the immigrant population as a whole, this share is around 16%), while the percentage of minors (18%) is considerably low, compared with 24% for all regularly residing non-EU citizens (Ministero del lavoro e delle politiche sociali 2016). Over seven out of ten Moldovans live in Northern Italy, especially in the North-East (with a single region, Veneto, where 27% of the total are concentrated, and with significant communities also in Lombardy and Piedmont). Next comes the Centre (about 21% of the total located in Emilia-Romagna and relevant presence in Lazio and Tuscany) and finally the South, with a marginal share of around 3% (almost totally in Campania) – see Figure 2.

The Moldovan population is also somewhat de-concentrated across many Italian cities. While many reside in Rome (more than 8,600), the majority of Moldovans live in middle-size provincial towns located in Veneto, Emilia Romagna and Lombardy: Parma (5,000), Venice, Padua, Bologna (over 4,000), Verona, Brescia, Modena, Reggio Emilia (3,500–1,500) are with the bigger cities of Turin (4,500) and Milan (3,000) in the top ten (ISTAT 2016).

Such geographic deconcentration is partly reflective of a slow rise in the diversification of employment sectors of Moldovans. Domestic assistance and personal services is still the dominant sector (53% of those working, see Graph 2) but other major sectors of economic activities are increasing, including industry and construction (18%), transportation and business services (12%), and wholesale and retail trade (11%). Crucially, domestic work has not been as deeply affected by the Italian economic crisis as other sectors and, consequently, the large number of women employed as caregivers may have mitigated the negative impacts on job levels for Moldovans: in 2015 the unemployment rate was 15% (about 20,000 jobless people).

Overall, 67% of the Moldovan population in Italy aged between 15 and 64 are employed. This is 9 percentage points higher than the rate recorded for non-EU citizens taken as a whole. This may reflect the relative age composition of the population and the positively selected educational profile (the majority of Moldovans employed in Italy have a medium to high educational qualification, with 64% holding an upper secondary school certificate and 18% a university degree). However, that said, the prevalent area of Moldovan employment is unskilled and skilled manual labour, performed by 97% of Moldovans workers, compared to 3% of the total who are executives and professionals. The number of Moldovan owners of individual firms in Italy totalled 4,600 at the beginning of 2016: a low rate in absolute terms, but with a promising growth prospect if compared with the previous years.

The Moldovan community in Italy illustrates the diversification of migration strategies we introduced above. More than 65% of Moldovan migrants in the country hold a long-term residence permit. The increasing percentage of minors who have joined their parents abroad thanks to a residence permit for family reunification and the growth of a second generation born in Italy have together driven the number of Moldovan students in Italian schools up to 25,000. One out of three of these Italian-Moldovan youngsters are enrolled in the upper secondary school, with 80% of them attending technical and vocational programs (Ministero del lavoro e delle politiche sociali 2016).

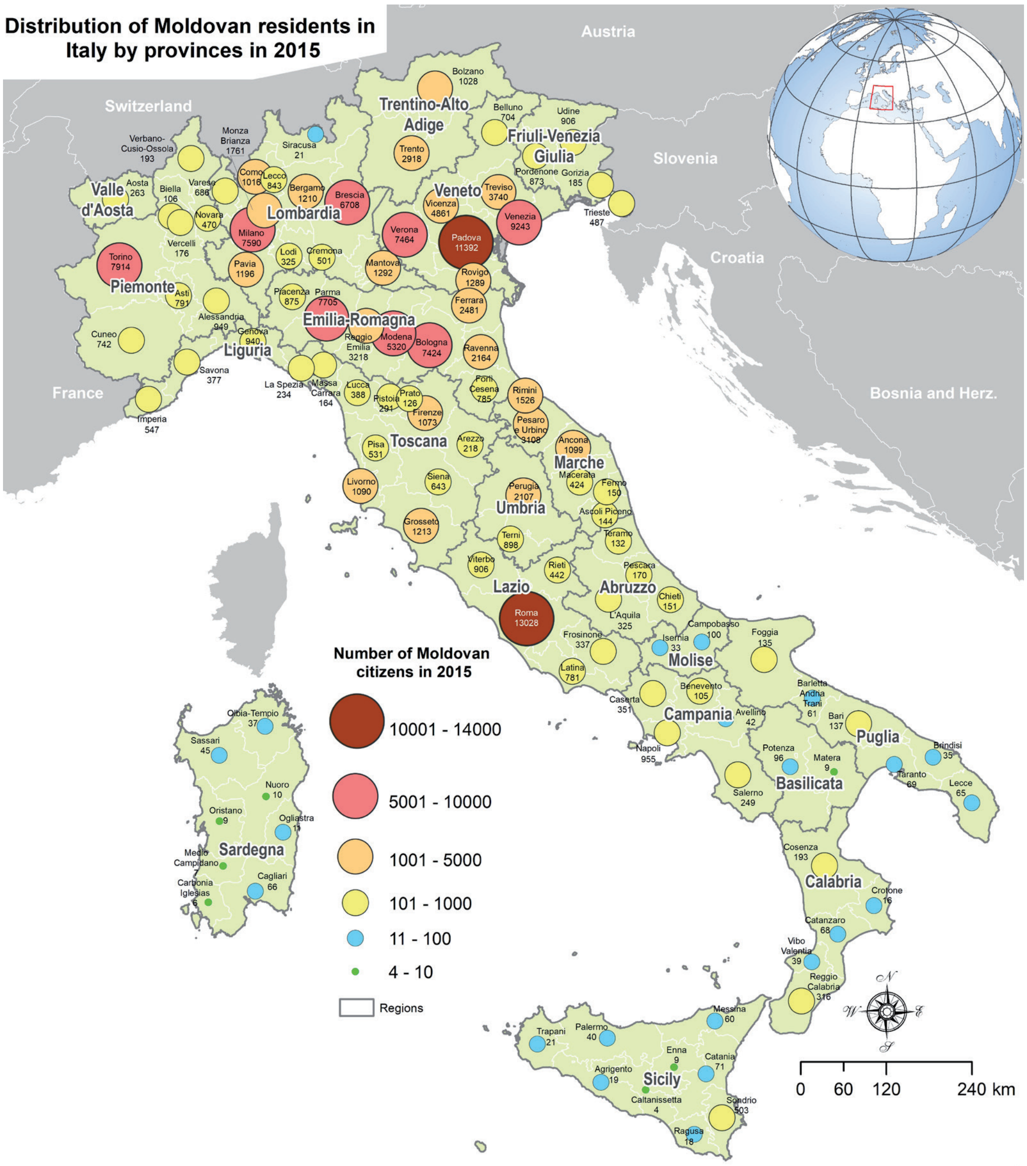
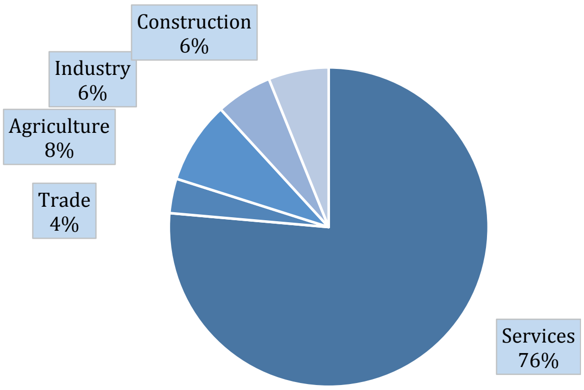


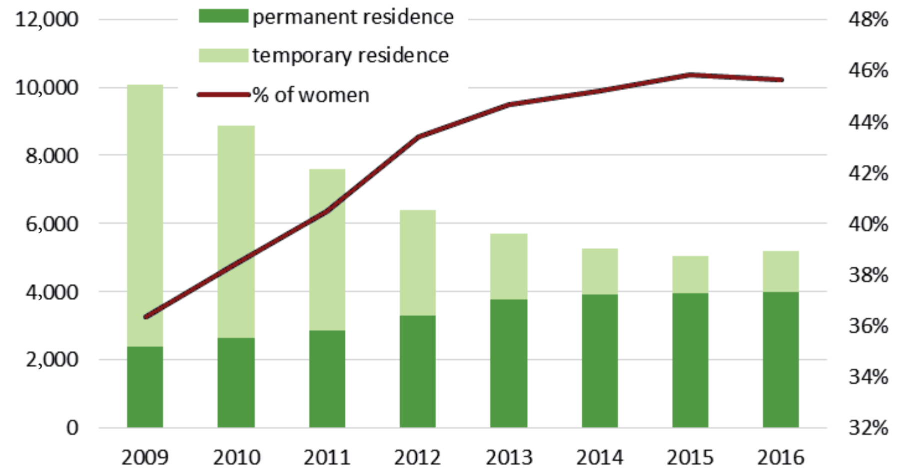

**Fig. 2** Moldovan migrants in Italy by provinces, 2015. Source: ISTAT (2016).




**Graph 2** Moldovans in Italy by occupational status. Source: Ministry (2016a).

## 3.2 Czechia

Sustained Moldovan migration to Czechia is more recent than Moldovan migration to Italy, increasing only after 1989. Along with other streams of immigration to Czechia, Moldovan migration continued to grow until 2009 when the global recession increased the restrictions Czechia placed on immigration (ČSÚ 2016). As Moldovans in Czechia were considered "standard" economic migrants they were particularly impacted by restrictive




**Graph 3** Moldovans in Czechia by gender and type of residence, 2009–2016. Source: Ministry (2016b).

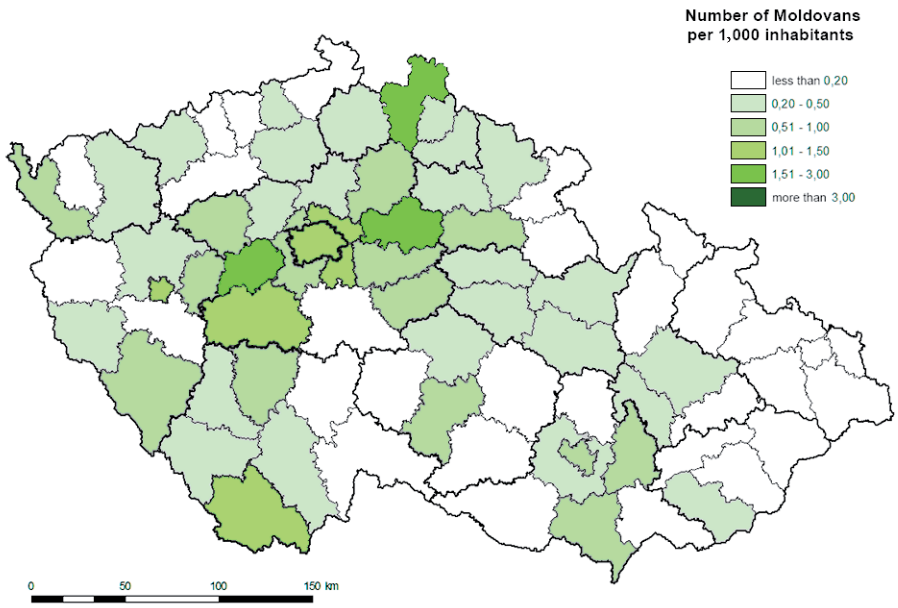



**Fig. 3** Moldovans per 1,000 inhabitants by Czech districts, as of 31 July, 2016. Source: Ministry (2016b).

measures targeted at economically active foreign workers (Valenta, Drbohlav 2014). The overall number of Moldovans in Czechia has dropped by almost 50% from 2009 to 5,182 in 2016. There may be some signs this decline has now ended and numbers are stabilizing (see Graph 3).

While the overall number of migrants is less than in Italy, there are important shifts in the gender composition of the Moldovan population. What had been an overwhelmingly male population had become, by 2016, more gender balanced, with women counting for 46% of all Moldovan employees, and 46.5% of all Moldovans in Czechia. As in Italy before 2002, this ratio may still be an undercount of women Moldovan workers in Czechia (see e.g. Ezzeddine et al. 2014) While lower than the ratio in Italy, it is higher than the ratio for other immigrant groups in Czechia, which average 36% female and 64% male. There are at least two possibilities for this trend. First, the continued feminisation of emigration from Moldova may have led to the identification of Czechia as a place of employment for care workers. Second, Moldovans may be pursuing a different integration strategy leading towards more family-based reunification possibly to access employment visas over the long term. In fact, the permanent residency (i.e. family-based migration) of Moldovans has been growing in both relative and absolute terms. The age composition is broadly similar to other foreign employed groups in Czechia. 50% of Moldovan employees are in the age group 31–45, 2.5% are younger than 20, and 16 per cent of them are older than 50 years (the corresponding figures for all foreign employees are 44.5%, 3%, and 18%, respectively).

In geographic terms Moldovans appear concentrated in central region of Czechia (Figure 3) with eastern and Moravian parts of Czechia home to fewer Moldovans. The district with the highest share of Moldovans compared to total population is Liberec (2‰) followed by Nymburk (1.9‰) and Beroun (1.8‰). In terms of the Moldovan population per se it is mostly concentrated in the biggest cities in Czechia. Almost 30% of the community is based in Prague, just over 6% in Liberec, 4.5% in Plzeň, and 3.8% in Brno and Nymburk each.

The structure of employment of Moldovans follows the overall figures on migrant employment in Czechia, notwithstanding any undercounting of particular groups as above. Major sectors of employment (NACE system)

**Tab. 1** Major sectors of economic activity of Moldovans (employees) in Czechia, as of 31 July, 2016.

| Sectors of employment (CZ – NACE) | | Share of Moldovans on overall foreign employment |
|---|---|---|
| **Manufacturing** | | **32.7%** |
| | Production of iron products | 19.9% |
| | Food industry | 11.1% |
| | Car industry | 9.5% |
| | Electrical industry | 8.4% |
| | Production of plastics | 7.9% |
| | Production of machinery | 6.9% |
| | Other | 36.3% |
| **Construction** | | **13.1%** |
| **Wholesale and retail trade** | | **12.3%** |
| **Agriculture, forestry and fishing** | | **10.6%** |
| **Administrative and support service activities** | | **10.5%** |
| **Transportation and storage** | | **5.3%** |
| **Other** | | **15.5%** |

Source: Own calculations based on OKSYSTEM (2016).

**Tab. 2** Economically active Moldovans according to type of economic activity in Czechia, 2011–2016 (July).

| | | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 (31 July) |
|---|---|---|---|---|---|---|---|
| **Moldovans** | **Entrepreneurs** | 1,585 | 1,279 | 959 | 802 | N/A | **716** |
| | **in %** | 37.2% | – | – | 28.1% | – | **20.4%** |
| | **Employees** | 2,671 | N/A | N/A | 2,053 | 2,464 | **2,800** |
| | **in %** | 62.8% | – | – | 71.9% | – | **79.6%** |

Source: Ministry (2016), own calculation based on OKSYSTEM (2016) data.

**Tab. 3** Status of Moldovans in employment in Czechia by the CZ-ISCO, as of 31 July, 2016.

| CZ-ISCO category | | Moldovans | Total foreign employment |
|---|---|---|---|
| 1 | Managers | 1.2% | 3.4% |
| 2 | Professionals | 3.1% | 11.4% |
| 3 | Technicians and associate professionals | 3.4% | 7.6% |
| 4 | Clerical support workers | 3.1% | 5.2% |
| 5 | Service and sales workers | 8% | 9.8% |
| 6 | Skilled agricultural, forestry and fishery workers | 1.3% | 0.5% |
| 7 | Craft and related trades workers | 16.8% | 13.9% |
| 8 | Plant and machine operators, and assemblers | 19.5% | 18.2% |
| 9 | Elementary occupations | 43.5% | 29.9% |
| 0 | Armed forces occupations | 0.1% | 0% |
| **Total** | | **2,800** | **355,235** |

Source: own calculations based on OKSYSTEM (2016).

are manufacturing, construction, and wholesale and retail trade (Table 1). The relatively high numbers of Moldovans (10.5%) in administrative and support service activities reflects some awkwardness of the classification – those counted in this sector are in fact employees of employment agencies and, thus, can in reality be employed in a variety of different industries. Furthermore, Moldovans predominantly work as employees in a company (Table 2). Crucially, the number of those listed as entrepreneurs has declined since 2011. As the global economic recession deepened, and Czechia sought to limit immigration, the number of Moldovans in Czechia in absolute terms declined significantly, while the share of unskilled partly decreased and of skilled workers actually increased slightly. In any case, the educational structure of employed Moldovans is less selective than foreign-born employees in Czechia. 42% of working Moldovans have a basic education compared to 30% of all foreign workers, while only 7.5% have a tertiary education compared to 17.7% of all foreign workers in 2016. The rather lower educational attainment of Moldovan workers in Czechia is further reflected by data on occupational status (ISCO classification is presented in Table 3). Moldovan employees show a considerable over-employment in categories with the lowest required qualifications.

## 4. Implications for Migration-Development Nexus

This section discusses how the preceding comparison of Moldovan migration in Italy and Czechia sheds light onto the concept of the migration-development nexus. In both countries Moldovans are a stable and important segment of the immigrant population. The population in Italy is larger (almost thirty times), longer established, more educated, more decentralized, and more feminised than the population in Czechia.

While Moldovan migrants to both countries are driven by socioeconomic considerations, of which livelihood remitting to family is key, Italy and Czechia have adopted very different migration policy regimes to manage mobility, and Moldovans have been impacted by this. In Italy a sort of "amnesty" in 2002 made the large population of women migrants visible. It may have been influential in leading today's high rate of family reunification and in the relatively resilient response to economic recession in 2009 when relatively few Moldovans left. By contrast, Czechia took a very efficient restrictive approach to temporary labour immigration following recession in 2009 which, in relative terms, decreased unskilled Moldovan migrants and, hence, increased skilled Moldovan migration slightly. In both countries, and beyond, Moldovan migrants have used increasingly diverse strategies to access work. This includes long-term or permanent residence permits, family reunification, and using Romanian identity.

We confirmed the expectation of the migration-development nexus (Faist 2004) that the Moldovan economy and, more widely, society depends upon migration and its financial remittances to combat socioeconomic problems. However, the extent to which migration policy is directly enabling development is less clear. We found that Moldovan international migration systems, and the strategies being used by migrants, are diversifying. Part of this diversification is geographic, with new destinations, including countries with no prior history of immigration, and those of the former Soviet Union. While migrants may choose destinations in accord with destination policy, in reality Moldovan cultural and linguistic affiliations affect patterns of migration. More widely, as remitting may be motivated by family considerations, not abstract macro-economic aspirations, it is planned over social horizons. This may be the reason for differential strategies of family reunification in Italy and Czechia.

These comparisons generate a series of research questions. For example, what are the mobility, employment, and transnational strategies of those Moldovans who have used family reunification in Italy and Czechia (Bailey, Boyle 2004)? Why has the Czech immigration policy led to a deskilling of Moldovan immigration? What are the long term prospects for development from migrant remittances? Without deep societal transformation changes in Moldova which must go hand in hand with improvement of the socioeconomic situation, emigration may continue with limited return to Moldova, with very limited positive effects upon development – only via remittances at an individual/family level and perhaps very limited and sporadic investments. In any case, no significant development would highly probably be visible at local, not to mention regional or nationwide levels (de Haas 2007b).

## 5. Summary and Conclusions

The general goal of our paper was to advance knowledge of contemporary Moldovan migration. With the deterioration of economic conditions since 1991, financial remitting has continued to be very significant, both to the overall economy and, increasingly, to many families for meeting basic livelihood needs. One in three Moldovan families are somehow affected by mobility as part of "an emigration culture". More women leave Moldova. Overall, Moldovan migration is diversifying, with new destinations, an expanded range of strategies for entering countries and accessing labour markets, and changing patterns of migrant selectivity, some seemingly affected by government policy. The global economic recession of 2008 had different implications for Moldovan migration patterns to and from Czechia and Italy.

Our specific objective was to assess these trends using the concept of the migration-development nexus. On the one hand, the concept provides a suitable explanation for why origin countries (Moldova), destination countries (Italy, Czechia) and migrants all perceive a "win-win-win" from financial remitting and, accordingly, orient their government policy and livelihood strategy respectively. However, as the case of Italy and Czechia make clear, social and political context matters, as Moldovans reacted very differently to global economic recession in these countries. To say that the nexus is a simple "pendulum" swinging back and forth is an unscientific and – in the currently charged political climate of migration debate – irresponsible characterisation of a diversifying and complicated migration system.

We thus end with a call for further research on the linked social and economic processes that make up the migration-development nexus, including social remittances (e.g. Levitt 1998[3]). To address these and other questions we need robust data that permit comparative

3 Simply defined – "social remittances are the ideas, behaviors, identities and social capital flow from receiving – to sending-country communities …" (Levitt 1998: 927).

analysis of international migration. For example, in the Czech context, what is the extent of under-reporting of female migrants from Moldova and, indeed, other origins? Given the rapid diversification of contemporary migration, such data is urgently required. Because it must be harmonized cross-nationally an appropriate balance between securing personal data records and disclosing scientific information for the good of the whole society will need to struck.

## Acknowledgements

This study was supported by the Czech Science Foundation project: "Moldovans in Prague (Czechia) and Torino (Italy) – migratory and integration patterns, financial and social remittances under scrutiny" No. P404/16-22194S.

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# DOPŘÍRODY! – GEOINFORMATION MOBILE APPLICATION

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**ABSTRACT**

Many people in Prague keep seeking a refuge in green areas within the city. Such a desire has inspired us to develop an app for cell phones that would be able to find natural areas in Prague. Users are navigated to the green spaces in real time and space. This article deals with the design and development of such app which has been aptly named DoPřírody! (To the Nature!).

To create such an app requires a sound systemic design and also connection with a number of different components. Technically, it is a geoinformation community system composed of database, server, and mobile parts. First, it was necessary to define natural areas. Second, database of such areas containing exact position, description, type, photos, etc. was created. The server part includes application modules that secure users management, area search, routing, navigation, etc. The mobile part consists of user interface for cell phones. Special attention is given to the design and creation of algorithm that calculates the appropriate route within the road network which serves as a base for the navigation. DoPřírody! is also compared with competing projects like Googlemaps, Mapy.cz and OSM. Route length, time required, and computing time are the basic elements compared.

DoPřírody! has all the features of a community system, i. e. logged-in users can contribute to further improvements. Anyone can update information on natural areas, upload more detailed descriptions, photographs, and comments. Thus, the whole system remains "live". At the present time there are some 80 users that have downloaded the free installation app on Google Play.

**Keywords:** android; network analysis; server; database; nature; mobile app

Received 28 March 2017; Accepted 1 November 2017; Published online 15 November 2017

## 1. Introduction

### 1.1 Motivation and chief aims

Many Czech cities boast large green areas within municipal boundaries; their positive effects on the quality of life is indisputable (Alcock 2014; Pondělíček 2012). Also the capital city of Prague, chosen as a test area for this app, has an exceptionally high number of natural or semi-natural biotopes (i. e. areas where the negative effects of human activities are minimal so far) (Kočí 2016). Such areas provide necessary space for a number of animals and plants including some protected species (ENVIS 2016). The urban green areas include parks, historically important forests, lines of trees, various protected areas, and spaces along water bodies. All these green areas contribute to the exceptional character of the city and create an attractive and special atmosphere.

How to find the most suitable and best available green area in a big city? Such that would best meet our expectations? Which is the easiest "escape way" from all the hustle and bustle? These questions can be answered using a mobile app that would help to find one's way when looking for a green area. At the moment there are a few web portals (with varying degree of quality and updates) that show and describe the green areas of Prague. For example, the Green Map of Prague (http://zelenamapa.cz) or Prague in Czech Atlas (http://www.czechatlas.com/prague). So far, however, there has not been any free app that would be available "in the field".

The article focuses on the role of modern technologies (based on geoinformatic platform) while designing and creating applications for cell phones. The authors strived to build the system in such a way so that in future it could be enlarged and improved by the users. A special algorithm has been created to calculate the shortest route which could be compared with competing products, i. e. with Google Maps, Mapy.cz, and OSM.

Such app requires a sound systemic design as well as links to many various components. Consequently, the app forms a part of a community geoinformatic system that consist of three mutually interconnected components:

1) Database of natural objects (areas, entrance points);
2) Algorithms and modules for data search;
3) Application part:
   a) mobile app,
   b) website (with database administration).

The system has been named DoPřírody! (To the Nature!), thus reflecting its character. It is available to the public for free as an app that can be downloaded at Google Play and also as a website. The app works on cell phones, users can find their way to natural areas on the territory of Prague. As it works as a community system, it is easy to add, edit, and share natural areas using the app

https://doi.org/10.14712/23361980.2017.20
Čábelka, M. – Jakl, M. (2017): DoPřírody! – geoinformation mobile application
AUC Geographica, 52, No. 2, pp. 249–257

(or website). The system can be accessed at http://mjakl.cz/doprirody, the application at Google Play.

Such a system did not exist among mobile apps so far. The article describes its design, creation of individual components, and mutual interconnectivity of the whole system.

### 1.2 Why Android operating system?

Android operating system is widespread among users, support and tools are readily available for computer programmers – that is why Android was chosen as platform for the application. Android has become the market leader in the field of mobile devices, at the moment it has more than 80% of the market (iOS 18%, Windows Phone 1%) (Mikudík 2016). Most software developers have focused on Android; consequently, a number of tools enabling easy and intuitive development of new applications came to existence, often aided by a huge amount of instructions and advices on different message boards.

Developing different applications for Android using JavaScript is a recent, dynamic field, featuring fast and unorganized emergence of new trends and practices. It is, however, also an attractive and modern subject with a whole plethora of authors and innovators (Appfigures 2015; Grant 2013; Konečný 2017). Android provides complex solutions for manufacturers and software developers. Instruction manuals, message boards, as well as tools intended for developing new applications are in general free – Software Development Kit (SDK) (Android Developer 2017). As printed material dealing with the above topic quickly becomes outdated, information was chiefly obtained from electronic sources and instruction manuals.

They are mainly technical universities, that specialize in the production and development of Applications for Android. That is way the scientific works produced mainly on technical universities (Kalčík 2013; Šarata 2015; Krejčí 2015; Njunjic 2012) proved to be a valuable source of inspiration and information.

### 1.3 System architecture

The system requires an uninterrupted communication between client's application and remote server. In order to optimize the pressure, three-layer model "client–server–database" was adopted. Client's app sends queries to the remote server, which has a much higher capacity and provides all computations. Afterwards, results are sent back to the client's app and displayed to the user. All data are stored in the relational database and made accessible to the server.

Such a three-layer architecture is currently used by a high number of applications that deal with data, i. e. by a substantial portion of modern company applications. Compared to the now outdated two-layer client–server model, the three-layer systems allows a better performance distribution among clients' devices and server; thus, client's applications can work even on the cheapest devices (Güner 2005; Techopedia 2015). The author and users appreciated this feature many times during the creative process and testing. For example, any reported problem with the server or database could be centrally fixed without the necessity to create updated versions of the app.

Unlike the server, requirements for client's application are low and these usually work trouble-free also on low-performance devices. Both the web application and the application for Android utilize the same server core of the system. The graphics of the final "product", however, are different, depending on the design abilities and operating modes of different devices.

The server part of the system and the database must be carefully protected – fact that may be seen as a disadvantage. Server must be very stable plus quality internet connection between client's application and server must be secured during the whole period of use. Relatively frequent failures of the database server (caused by the webhosting provider) proved to be a big problem. When such a failure occurs, the client's application and the whole system become unavailable.

## 2. Data preparation, database design

Precise localization of natural areas makes up the key part of the system. In order to create database of natural areas, first it was essential to define "natural area" as such including different types and qualities.

### 2.1 Data on natural areas

Scientific sources cite a number of ways how to define natural areas (Deslauriers et al. 2017; Udržitelný rozvoj 2016). As the system has been developed on a community base, it became necessary to produce a new definition understandable for casual users. The following formula indicating natural areas was chosen:

Natural area is such a type of public space (accessible for free or subject to charge) that can bear at least 10 to 15 mature trees on a continuous green space. Visitors can hear birds singing and feel (at least seasonally) the scent of flowers there.

Field research has revealed that the above definition includes also some rather extensive areas with scattered trees and plants among solid surfaces (tarred roads, cobblestones). On the other hand, some small, yet environmentally valuable parks, plus vegetation along water streams also fit into the definition. The database is further divided into five subtypes that can be (de)activated by users:

**Park/garden** – Areas significantly altered and maintained by humans on a regular basis. These are mostly city parks and gardens, including large green areas within city squares.

**Tab. 1** Table stored in database (example).

| ID | Name | Type | Play ground | WC | Dogs | Submitted _by | Entry | Bench | Food | Sport | Light | Tree | Wheel chair | Bike | Run | Nature_Trail | Description | Region | Prot. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | Folimanka | Park | 1 | 1 | 1 | Majkl | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | | Praha 2 | 0 |
| **2** | Na Karlově | Park | 0 | 0 | 0 | Majkl | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | | Praha 2 | 0 |
| **3** | Ztracenka | Park | 0 | 0 | 0 | Majkl | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | | Praha 2 | 0 |
| **4** | Havlíčkovy sady | Park | 1 | 1 | 1 | Majkl | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | | Praha 2 | 0 |
| **6** | Albertovské stráně | Park | 0 | 0 | 1 | Majkl | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | Praha 2 | 0 |
| **7** | Náměstí Míru | Park | 0 | 1 | 1 | Majkl | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | | Praha 2 | 0 |
| **8** | Karlovo náměstí | Park | 0 | 1 | 0 | Majkl | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | | Praha 2 | 0 |
| **9** | Botanická zahrada UK | Botz | 0 | 1 | 0 | Majkl | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | | Praha 2 | 0 |

**Forest** – Areas covered by dense, fully grown trees intended for economic or recreational purposes. Forests often play a key role in the landscape biodiversity. In most cases, forests are found outside cities or at city margins.

**Cemetery** – A special transitional type between park and forest, with graves and memorial places. Dogs and activities related to sport are often not allowed. Some users may not be happy to visit such areas; deactivation is possible.

**Botanical garden** – A special transitional type between park and orchard with a broad array of (exotic) plants, often kept in greenhouses. Such areas are usually subject to entrance fee. Botanical gardens may be preferred by some users; however, it can be deactivated, too.

**Other green areas** – All other types of green areas like meadows, pastures, vegetation along water streams, roads, and railways, etc. Any other areas covered by plants.

Several criteria that can be clearly assessed were chosen (illumination, benches, playground, entrance fee etc.). These allow users to narrow the search for appropriate area.

### 2.2 Creating the database

Relational database MariaDB was chosen as data storage device for DoPřírody! system. It presents a more advanced branch of MySQL developed on a communal base. The features of GNU GPL free software licence are respected (Wikipedia 2016). This database is compatible with MySQL and can be implemented on the webzdarma.cz servers that host the whole system. The structure of data storage within the relational database includes a number of tables (Kolář 1998; Zajíc 2016; PHPMyAdmin Team 2017).

The system base consists of tables that include data on natural areas and entry points. The first one of this double table features data on natural areas with all details; geographical location, however, is not included (Table 1). The second table – database of entry points to respective areas – includes geographical coordinates only. Areas and entry points are linked together using primary key (ID) (Figure 1).

Road network data are divided into sub-networks and stored separately for each area. Each sub-network includes table of nodes and table of road network edges. These are linked together using IDs of respective nodes that feature geographical coordinates. Each road network edge bears only the information on starting and final node (these nodes can be switched when required). System of sub-networks allow to reduce the data volume used by algorithm when computing the shortest way towards selected object.

Users' feedbacks and reviews form a very important part of the system. These are also sorted into tables and used by different system modules. Administrators only can make use of the "log" table that trace the users' activities within the system: all editing, new entries, and new registrations are stored here (Figure 1).

## 3. Server part of the system

Server forms the key part of the whole system. Server provides most computations, it receives all the information from client's applications, communicates with the database, and sends feedbacks to the users. Components of the server application part are divided into several modules that maintain intensive mutual links for the sake of easier creation and management. Each module includes one (or more than one) entry, processing, and exit pages with algorithms using the PHP scripting. Depending on requirements, modules can access tables stored in the database.

**Users' management module** – Provides registrations of new users and management/editing of registered users. Certain procedures offered by the system (updates of natural areas and entry points, etc.) require registration

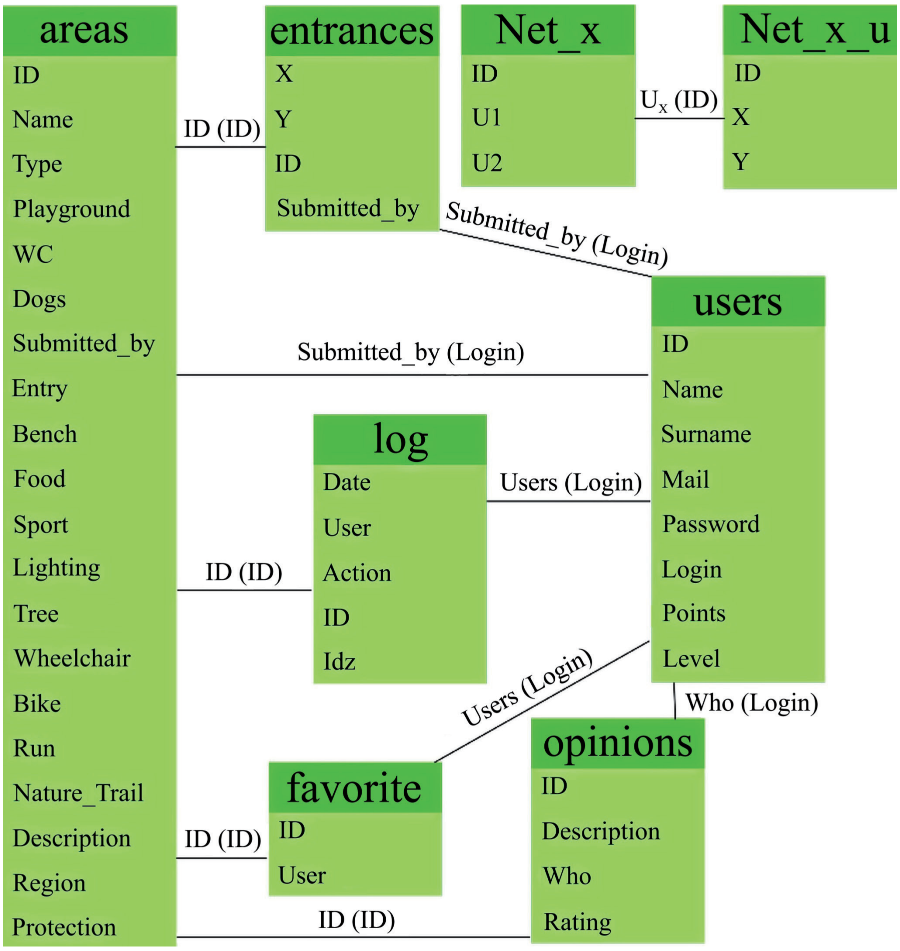


**Fig. 1** Mutual links among tables ("x" indicates respective sub-networks within the database).

to secure safety and control. This module is firmly integrated and mutually linked with other modules. It provides users' authorization and records points that can be obtained by users for selected activities (thus motivating users to improve the system).

**Area search module** – One of the key modules. It receives users' requirements for the areas searched, creates SQL query, and consequently selects matching areas from the database. It also chooses the nearest (crow-flight) entry point for each of the selected areas. This is shown on map.

**Route and navigation module** – Secures the shortest way leading to selected object. When the routing can make use of the road network stored in the database, computation utilizes own algorithm (see below). The GPX file is subsequently visualized on map. When the routing includes sections that are not part of the database, users receive an aerial navigation supplemented by another route created by Graphhopper algorithm using Leaflet-routing-machine on the OSM network (Liedman 2016). This module also allows tracing in real time, and – if necessary – recalculation of a new, more suitable route.

**Detailed module** – Provides detailed list of all features of the selected natural area. This also includes pictures that are assigned to respective areas by areas ID stored on the server. The module allows registered users to input feedbacks and comments.

**Update module** – It is closely linked with the detailed module. It allows registered users to update their comments and to alter area descriptions.

**Add module** – Community based system requires that users could extend the database of natural areas and entry points. This module registers new data into the database of areas / entry points.

**Favourite areas module** – Registered users can add selected natural areas among favourites. Hence, client's application allows users to browse through his/her favourite areas plus areas that he/she reviewed, updated or added to the system in the past.

**Help module** – Fully integrated, essential module that makes the whole system coherent. Provides guidelines how to use other modules.

**Information and statistics module** – Fully integrated module with high internal heterogeneity. It collects and stores information on quality and speed of route planning, on the number and location of natural areas in the database. This module informs users about system updates and changes within the system core and client's applications. It also secures clients' feedbacks.

**Administration and management module** – It can only be used by the author and allows easier management of the system. The module includes different management tools, it also registers all users' activities within the system.

### 3.1 Maps

Maps form the initial or final parts of some modules. Projection of suggested routes into the map proved to be an uneasy task with a number of possible solutions. It was intended to use the same projection type for web client and for Android mobile app. That is why JavaScript library Leaflets, enhanced by plugin from Maxim Petazzoni for GPX files, was chosen (Petazzoni 2016). This solution works excellently in both client's applications.

### 3.2 Finding the shortest route

The algorithm responsible for finding the shortest route in the road network stored in the database presents the crucial and most complicated of all algorithms within the system. In theory, some of the existing algorithms may have been used (Berg et al. 2008; Algoritmy.net 2016; Friebelová 2011; Hliněný 2008). However, as the system has a number of special features (frequent transitions among different sub-networks, etc.), a new, tailor-made algorithm that would fully fit specific requirements of the system posed a challenge. The difference between our algorithm and the often used Dijkstra algorithm is that the Dijkstra algorithm scans all network points. Problems that arise include, for example, blind trips and possibly over-encryption. (Kolář 2004; Cormen et al. 2001). Creating a new algorithm also allowed a new innovative approach that can address problems of navigation in the road network.

The search algorithm is triggered immediately after user selects the object that should be reached; the search for best routes can start.

If the selected object was too far from the nearest part of the route network (more than 500 metres), the route is shown on crow-flight basis and supplemented by visualisation that utilizes Graphhopper algorithm the OSM data. If the user's position was near the road network stored in the database, the algorithm works as follows:

1. The surrounding is detected – Database network is not continuous, thus the unnecessary parts can be ruled out at the beginning which speeds up the computations.
2. Catching up with the road network – The nodes nearest to start and selected object are found. In this way algorithm is "attached" to respective nodes and can proceed to find the best.
3. Sub-network selection – A sort of a special "switch" allows that algorithm could pass through different sub-networks while conducting iterations. This file switches among different sub-networks depending on the node or edges names.
4. Movements within the sub-network system – This section of the algorithm forms the main iterating part. Operations are repeated till the node (identified as the target node) is reached. The algorithm is located at position S (Figure 2) at the beginning of this cycle. All road network edges containing this point (initial or final one) are found in the database.
   a) Linear movement – It follows if the S point was found in less than three road network edges. If S point was the closest point to the user' position, algorithm would move in a direction that brings it closer to the selected object (target). In all other cases the algorithm is already moving in a certain direction (from S – 1 point); consequently, it will continue in the same direction (towards S + 1 point) and not vice versa. The S + 1 point would further become a new "starting point" S and its coordinates are recorded into GPX file. If the S + 1 point was not yet the final desired node, the iteration continues.
   b) Intersection – If the S point was found in three or more road network edges, the algorithm has reached an intersection and continuation will be a bit more complicated. If the S point was found in four road network edges, three possible further directions exist (the S – 1 point is omitted). First, the algorithm identifies the number of edges that contain each of three $S_x$ + 1 points. In case any of the $S_x$ + 1 points would be identical with the target, the algorithm moves directly towards point 5).
      I. Dead end edge – If the $S_x$ + 1 point was found in one edge only, it must be a dead end. Such point is omitted in further calculations and the next node is examined (in this case only two more candidates for an appropriate S point exist).
      II. Familiar node – Sometimes happens that in the past the algorithm already examined the selected $S_x$ + 1 point. Such node is also excluded from further calculations to avoid unwanted circulations.
      III. Direction preference – If the $S_x$ + 1 node fits the above criteria, the following parameters are calculated: distance from the object (target), distance towards the midway point between starting and final point, and the angle between two lines (connection S – 1 and target, connection $S_x$ + 1 and target). Sum of these three variables makes up the final "score" of $S_x$ + 1 node and it is compared with other possible candidates. The node featuring the lowest "score" (i. e. the one which is closest in the possibly straight direction) will be selected as a new S point. Its coordinates are recorded into the GPX file.

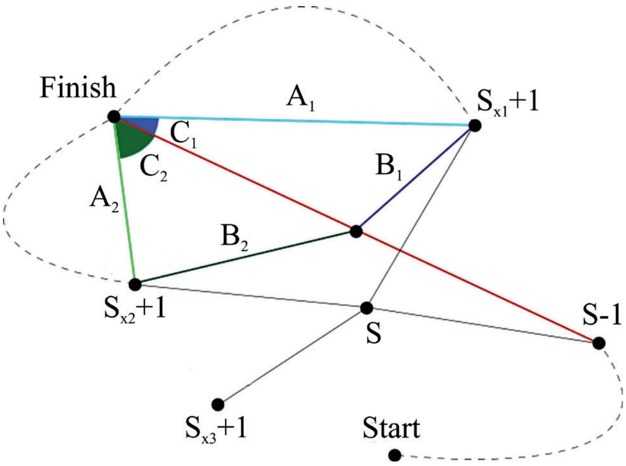


**Fig. 2** One step of the navigation algorithm (diagram)

IV. Safe return – Sometimes algorithm selects a straight direction which may, however, later reach a dead end. It also may happen that no further continuation is possible beyond an intersection (usually due to the rules described under i and ii). As two movements through the same node are forbidden, the algorithm must return one step back. It goes back to the last intersection (the visited intersections are registered; this is the only exception when algorithm is allowed to enter again the already visited node) and moves in a different direction. If even such a movement was not be possible, the algorithm must further "reverse" until it finds a possible onward route.

"Reversing" means that the GPX file contains error points which creates a messy network. Thus, the unused nodes must be deleted from the GPX file. When the algorithm reaches the same intersection second time – let it be node No. 2751 –, all points registered after the first visit of the node 2751 are deleted from the system. Consequently, the final route consists only of "successful" steps of the algorithm.

5. Reaching the destination – After having reached the final node, user is redirected to the map page where the route is shown. Information on the route length and time required to reach the destination (by walking) is displayed, using the Leaflet, plugin GPX functions. Time needed to cover the distance is based on the average speed 4,500 metres per hour (75 metres per minute). In other words, one meter of distance equals to 0.8 seconds (or 0.013 minute).
6. System failure – Under certain circumstances, failure may be triggered purposely as a safety brake. When the algorithm "gets lost" in the network (i. e. needs to reverse a number of times and computation takes a rather long time), the process is terminated by an error message. System failure is recorded into the internal files.

## 4. Client's application

Mobile client's application uses the very same websites and scripts as client's application for PC. The size of display, however, is fundamentally different (20″ vs. 5″) and the same applies to connection speed (tens of kb per second when using GPRS/EDGE vs. fast connections of hundreds of MB per second). As a result, it became necessary to secure appropriate formatting for mobile application (Figure 3). Thus, the system includes two different CCS styles: one secures correct appearance of the web app, the second one that of the mobile app. Each URL sequence in the mobile app is followed by information that results optimized for cell phones are required.


**Fig. 3** Optimizing the first page for web browser and cell phone (example).

WebView components that enable to display websites (Android Developer 2016) secure communication with the remote server. Adding GET strings behind URL pages or sending data by the POST method allow to create users' queries. WebView components are widely used in many activities and often are integrated into the activity core in such a way that users can not distinguish between parts generated by the website and those that remain part of the activity core.

Another advantage of the mobile app is that the user's log-in details can be stored in the system. Consequently, registered users enjoy immediately all privileges without the need to fill in the log-in details again and again. This works also in case that user would like to log in on a different device.

Different languages are easy to implement in the Android client's mobile app. All captions are displayed either in Czech (if Czech was set as the prime language) or in English (for all non-Czech languages). Information on the language used is being sent to the server with each URL address and texts in the same language are produced.

## 5. Community character of the system, distribution, safety features

The two modules that enable addition of natural areas including entry points and users' management are essential for the open character of the system. Registered users can rate the respective natural areas, leave comments, and update information. New natural areas and entry points can be added either using the web application or directly in the open field with the client's app for cell phones. Users can communicate with the author, report imperfections, and share ideas that may lead towards further improvements.

The open character of the system which allows easy editing and adjustments by users, however, also brings a high risk of hacking. Thus, high level of data security consisting of several tiers is necessary. All users' passwords are encrypted. All operations when users input data for communication with the database are protected against SQL-injection attacks. There are special scripts integrated into the system that can immediately and permanently block IP address of anyone with irregular behaviour.

No web / system security, however, can be absolutely perfect. For the sake of safety, full backups of database and scripts are provided regularly.

## 6. Conclusions – comparison with competing systems, practical use

The ability to find the shortest route leading towards selected destination forms the most important feature of the DoPřírody! system. The best way how to test quality of the algorithm used would be to compare it with widely used web mapping services. Inside information on algorithms and computing processes used by services like Mapy.cz or Google Maps, however, are not available to the public; consequently, a detailed comparison is not possible.

To provide an approximate comparison at least, routes suggested by DoPřírody!, Google Maps, Mapy.cz, and OSM were tested on a number of examples – always between the same starting and end points. Some of these comparative analyses are shown in the appendix.

Comparisons show that the algorithm used by DoPřírody! provides results that are fully competitive with those offered by the big commercial services. However, due to the strictly geographical logics of DoPřírody!, in some cases the algorithm may suggest a slightly longer route.

The time needed for computations (which is longer compared to the big competitors) remains the only real imperfection of DoPřírody!. However, the speed can be increased in future by implementing of a few planned improvements. Though DoPřírody! can not secure 100% success as regards the final route so far, the last updates reduced the system failures to a minimum. At the moment, routes are displayed successfully in 92% of cases.

In the case of failures or excessively long routes, analyses mostly showed that it is the road network – not yet complete – that is responsible for imperfections. Still, under most circumstances the algorithm used by DoPřírody! brings results comparable with big mapping services.

At the very beginning, there were a number of "grey zones" and unclear solutions. These gradually disappeared as the work was advancing. With the growing amount of work also experience mounted and even some "dead ends" brought new ideas, modules, and better solutions that helped to enhance the already existing parts of the system.

Hundreds of hours spent on developing DoPřírody! brought invaluable experience regarding databases and Android-related web programming. Users' feedbacks reveal potential for future development. The work on DoPřírody! triggered developing of many other mobile apps, some with commercial character (geolocation game Real World RPG – www.realworldrpg.info; app developed for Turistické známky and TéTetka collectors; app for participants of Závod tří vrchů – ŠerLok, etc.). These are currently used by hundreds of people.

## 7. Appendix – comparison with competing services

The route displayed in the following figures (maps) connects Prague Castle (50.090 N, 14.400 E) with Vinohrady (50.074 N, 14.444 E), i. e. it crosses much of the territory Prague 1 and Prague 2. DoPřírody! was primarily developed for these city parts. The route was calculated by four services: Mapy.cz, Google Maps, Graphhopper.com, and DoPřírody! The time needed for calculation was measured three times each; average of the three is shown. Tables include comparison of other routes.

**Mapy.cz** – shortest route 4.4 kilometres, estimated walking time 75 minutes, computing time ca. 2 seconds.

**Google Maps** – shortest route 4.5 kilometres, estimated walking time 59 minutes, computing time ca. 3 seconds.

**Graphhopper.com** (OSM data) – shortest route 4.4 kilometres, estimated walking time 53 minutes, computing time ca. 3 seconds.

**DoPřírody!** – shortest route 4.5 kilometres, estimated walking time 59 minutes, computing time ca. 6.5 seconds.

**Tab. 2** Start 50.075 N, 14.420 E, end 50.082 N, 14.424 E

| Service | Distance (km) | Walking time (min) | Computing time (s) |
|---|---|---|---|
| Mapy.cz | 0.876 | 0:13 | 1 |
| Google maps | 0.900 | 0:11 | 2 |
| Graphhopper.com | 0.895 | 0:11 | 1 |
| DoPřírody! | 1.063 | 0:14 | 2 |

**Tab. 3** Start 50.069 N, 14.450 E, end 50.078 N, 14.431 E.

| Service | Distance (km) | Walking time (min.) | Computing time (s) |
|---|---|---|---|
| Mapy.cz | 1.800 | 0:34 | 2 |
| Google maps | 1.800 | 0:25 | 2 |
| Graphhopper.com | 1.860 | 0:22 | 1 |
| DoPřírody! | 2.102 | 0:27 | 3 |

**Tab. 4** Start 50.073 N, 14.410 E, end 50.077 N, 14.439 E.

| Service | Distance (km) | Walking time (min) | Computing time (s) |
|---|---|---|---|
| Mapy.cz | 2.400 | 0:42 | 1 |
| Google maps | 2.400 | 0:33 | 2 |
| Graphhopper.com | 2.410 | 0:29 | 1 |
| DoPřírody! | 2.455 | 0:32 | 3 |

**Tab. 5** Start 50.070 N, 14.430 E, end 50.090 N, 14.410 E

| Service | Distance (km) | Walking time (min) | Computing time (s) |
|---|---|---|---|
| Mapy.cz | 3.100 | 0:47 | 2 |
| Google maps | 3.100 | 0:37 | 2 |
| Graphhopper.com | 3.130 | 0:38 | 1 |
| DoPřírody! | 3.748 | 0:49 | 5 |

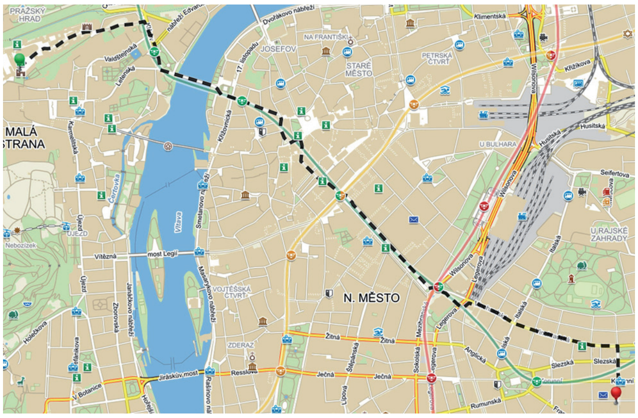


**Fig. 4** Route produced by Mapy.cz.

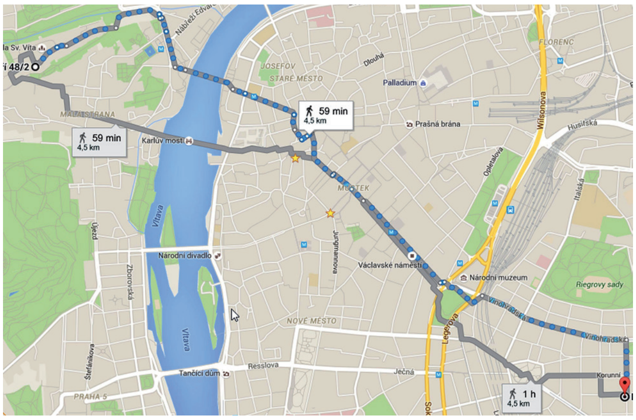


**Fig. 5** Route produced by Google Maps.

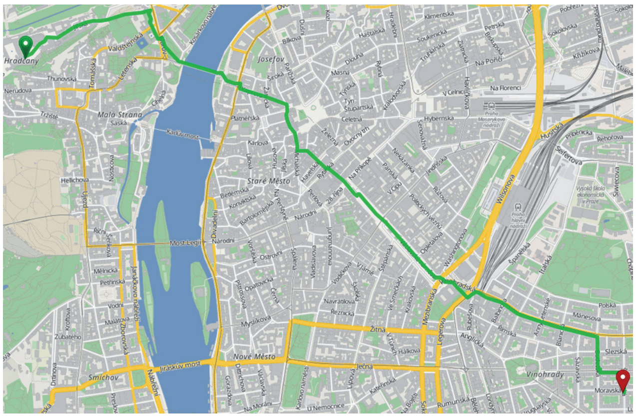

**Fig. 6** Route produced by Graphhopper.com.

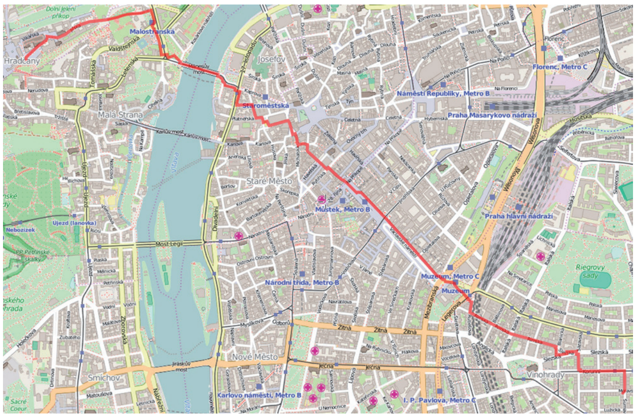

**Fig. 7** Route produced by DoPřírody!

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