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SUSTAINABILITY

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CRYOGENIC PROCESSES IN LOESS

ABSTRACT. This paper presents a new approach to the analysis of the genetic nature of the mineral substance of loessial rocks. At the present time, the prevailing view on this issue is the eolian accumulation of loess, while the influence of other factors of formation has not been practically taken into account. However, loess accumulation can be explained by other mechanisms, e.g., active processes of cryogenic weathering under a very harsh climate. The latter concept is based on the results of analysis of wedge-shaped structures in loess thickness, as well as numerous data of spore-pollen, microfaunistic, and other types of analysis. Further developing concepts of loess formation, the authors made an attempt to assess the degree of influence of cryogenic processes on the composition and structure of loess. The proposed method is based on a differentiated analysis of the distribution of the main rock-forming minerals (quartz and feldspars) along the granulometric spectrum. Two criteria are proposed – the coefficient of cryogenic contrast and the heavy fraction coefficient (i.e., the coefficient of distribution of heavy minerals) – which allow determining the degree of participation of cryogenic processes, as well as aeolian and aqueous sedimentation, in the formation of loessial rocks. This method was used to study two sections of loessial thickness – in the south of the Russian Plain and within the Loess Plateau of China. The results of the study revealed the role of cryogenic factors in the formation of the composition of the loess horizons of soil-loess sequences of different territories. Particularly clearly the effect of cryogenesis was manifested in the loess section in the south of the Russian Plain. In the section of the Loess Plateau, only the youngest deposits of the last formation stage are affected by cryogenesis. It follows that not only within the long-term periglacial permafrost zone, but also under the conditions of seasonal freezing in the Pleistocene, the processes of cryogenic transformation of deposits could have developed, which contributed to the formation of the composition and properties of loess of sufficiently high thickness.

KEY WORDS: loess, cryogenic processes, silt fraction, permafrost, seasonally frozen condition of ground

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INTRODUCTION

The so-called loess-soil formations are widely developed within the Pleistocene periglacial zone. They represent the alternation of loess horizons and buried soils. Most researchers [Krieger, 1965, Loess …, 1986, Velichko, et al, 2009] believe that cyclic climate fluctuations in the Pleistocene are recorded in the structure of loess-soil formations: soils were formed when biogenic sedimentation was predominant in warm interglacial and interstadial periods, while loess horizons accumulated in cold epochs, in the Pleistocene, during a sharp expansion of the permafrost area.

The prevailing view in the literature is that loess deposits have primarily eolian origin and they accumulated in the cold continental climate, when atmospheric circulation increased substantially [Krieger, 1965; Lessovye ..., 1986]. As a result, the atmosphere was saturated with dust; its content was 30 times higher than in warm interglacial periods. This conclusion is drawn from the analysis of the glacial cores of Greenland and Antarctica, in which an elevated content of micro-particles in the Late Pleistocene horizons of ice has been recorded. However, this can also be explained in another way. The horizons of glacial ice with an increased content of micro-particles correspond to the maximal temperature decrease, as evidenced by the isotopic composition of ice, which causes a decrease in snow precipitation, which, in turn, can lead to a relative increase in the content of micro-particles.

Some authors suggest that the activity of atmospheric circulation in the last glacial maximum should be studied separately for winter and summer periods. Mathematical modeling of changes in the atmospheric circulation of the glacial maximum showed that average wind speeds were particularly high in winter seasons [Lofverstrom et al., 2014]. In summer, the atmosphere had lesser cloudiness over the periglacial areas and a warm anomaly formed at the surface, i.e., in fact, the weather was anticyclonic. Thus, the activity of the eolian processes practically came to naught, despite very favorable environment, since the surface was clear from snow and the subsoil and soil were directly in contact with the air.

A very important argument of the supporters of the eolian origin of loess is its granulometric composition. Many researchers (Lessovye..., 1986) believe that silty and a very uniform granulometric composition of loess is the result of air sorting, in which dispersed mineral matter is carried by the wind in suspended state for long distances (up to several thousand kilometers) at a considerable height (up to three kilometers) from the Earth's surface. The subsequent processes of deposition of atmospheric dust represent, in their opinion, the basis of loess formation. One of the loess researchers, F. Zeiner (1963), wrote, "The eolian nature of loess is most simply revealed by its comparison with modern eolian dust." Fig. 1, reproduced from his work, shows the granulometric composition of various types of silty sediments. Eolian dust accumulated in the snow after a dust storm in the city of Wroclaw (Poland) (Fig. 1, A) is indeed very similar in the granulometric composition to the typical loess (Fig. 1; D and E). However, it also bears a great resemblance to the soliflual fine earth of Spitsbergen (Figure 1, B), whose origin is most likely cryogenic weathering; the eolian glacier dust has a much rougher composition (Fig. 1, C).

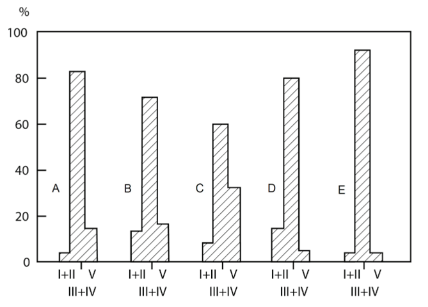


Fig. 1. The granulometric composition of various types of silty sediments (according to F. Zeiner, 1963).

Granulometric classes: I+II – 0- 0.01, III+IV – 0.01-0.07, and V – 0.07-2.0 mm. A - eolian dust accumulated in the snow after a dust storm, Wroclaw, Poland; B - banded solifluction soils, Svalbard; C - eolian dust accumulated on the surface of a glacier, Spitsbergen; D - young loess Saint-Pierre-lès-Elbeuf, Lower Seine, France; E - Mesozoic "loess" of the Triassic age, Bretten, Baden, southwestern Germany.

Another argument in favor of the eolian origin of loess, according to the proponents of this view, is the morphoscopic structure of quartz particles that compose loess. Virtually all quartz grains 0.5-1 mm in size, less often

0.5-0.25 mm, carry traces of mechanical processing in the air: they have a high degree of roundness and micro-pit and matt surface. At the same time, the surface of some grains has patterns associated with cryogenic processes, i.e., periodic freezing [Timireva, Velichko, 2006].

MATERIALS AND METHODS

The origin of 0.05-0.01 mm particles (the so-called loess fraction or coarse dust fraction) and of 0.1-0.05 mm particles, which together account for 70-80% of loess composition, is very indicative from the point of view of loess origin.

The well-known data of numerous soil and permafrost experimental studies show that under the impact of multiple freezing-thawing cycles on different types of deposits (sands, boulder loam, etc.), fractions larger than 0.25 mm degrade and a fraction of coarse dust (0.05- 0.01 mm) accumulates. This served as the basis for the ideas about the cryoeluvial nature of loess and its properties [Sergeev, Minervin, 1960; Popov, 1967].

The importance of frost weathering in the formation of loess was first noted by S. Wood in 1882-1889 [according to Krieger, 1965]. S. Wood suggested that loess was formed beyond the area of glacial development, in the permafrost regions under seasonal thawing, creeping, and slipping of the upper soil layers. When displaced, fine-earth products of frost weathering accumulated in low spots and depressions of the relief. Precisely such loamy deposits formed within Europe and North America were considered by S. Wood to be loess. However, S. Wood had a different view on the origin of loess in China because of its enormous thickness. S. Wood's hypothesis was repeatedly criticized, since his ideas did not explain a number of characteristic features of loess, in particular, its carbonate content. Nevertheless, S. Wood's concept on the distribution of loess mainly in the Pleistocene periglacial zone, or rather within the Pleistocene cryolithozone (the terminology that appeared much later), was supported and detailed by later works [Krieger, 1965, Konishchev, 1981].

To date, the differences between the two processes of formation of the dominant granulometric fraction of loess (0.05-0.01 mm) – whether it is the product of eolian differentiation of mineral matter and its sorting in the air, or it is the result of cryogenic processing of various types of parent rocks – are still unclear.

We proposed specific lithological criteria to identify cryogenic fine earth and products of its redeposition. Our approach is based on long-term studies of loess-like deposits in North Eurasia, in particular, the cover loess-like formations of the Bolshezemelskaya tundra, the northern part of West Siberia, and the deposits of the ice complex in the northern part of Yakutia, and the results of an experimental study of the cryogenic stability of the main rock-forming minerals [Konishchev, 1977, 1981].

This became possible only after it had been established that the stability series of the main rock-forming minerals (quartz, feldspar, mica) with respect to cryogenic weathering (the process of alternating freezing-thawing) is directly opposite to the stability of these minerals in temperate and warm climates. This general position was concretized through the determination of the cryogenic stability of monodisperse granulometric fractions of various rock-forming minerals (quartz, feldspar, etc.).

For the first time this approach was used in experimental studies of cryogenic stability presented in [Konishchev, Rogov, Shchurina, 1976] and later in research by [Minervin, 1982]. It was found that, under alternating freezing-thawing, the grains of quartz break down to the fraction of 0.05-0.01 mm, and the grains of feldspar, unchanged by earlier pelitization processes, are crushed to the fraction of 0.1-0.05 mm.

The differences in the limits of cryogenic disintegration of various minerals are due to the differences in the thicknesses and properties of unfrozen water films adsorbed on the surface of various minerals during their cryogenesis [Konishchev, 1981].

Thus, the position of the maxima of contents of the main rock-forming minerals within the granulometric spectrum of cryogenic fine earth (cryogenic eluvium) and the products of its nearest redeposition should not coincide and should represent a sequential series from larger to smaller particles: feldspar → quartz → minerals of heavy fraction. This cryogenic series is mirror-like to the scheme of mineral distribution within the granulometric spectrum of deposits of various facies-genetic types formed in humid conditions of warm and moderate climates, outside the zone of cryogenesis, established by fundamental research of N.M. Strakhov [Strakhov, 1962] (Fig. 2). As can be seen from the figure, within the range of the maximum mineralogical diversity limited by particle sizes 0.25-0.01 mm, the maxima of the mineral contents do not coincide. Therefore, it can be stated that the position of the main rock-forming minerals (primarily quartz and feldspar) within the granulometric spectrum is radically different inside and outside the zone of cryogenesis.

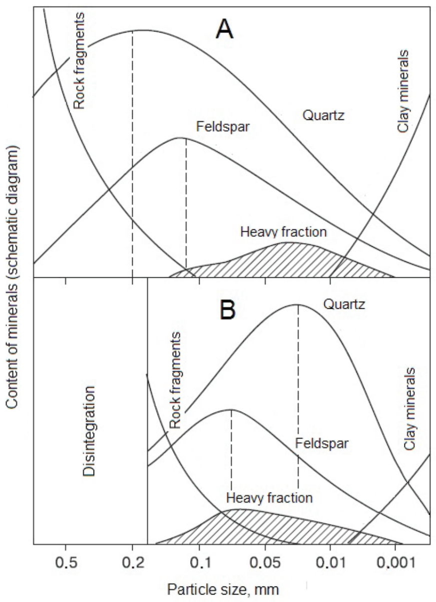


Fig. 2. Change in the content of minerals by grain size in dispersed rocks formed under warm climate conditions (A - according to [Strakhov, 1962]) and the zone of cryogenesis (B - according to [Konishchev, 1981])

Research on the composition of loess-like formations within the modern cryolithozone (the cover loams of the Bolshezemelskaya tundra and the ice complex of northern and central Yakutia) carried out by the authors have shown that only a differentiated approach to composition analysis allows assessing more objectively the cryogenic-climatic and facies-genetic conditions of the accumulation of mineral matter of these deposits.

A special coefficient was proposed as an explicit indicator characterizing the degree of participation of the cryogenic weathering process in the formation of deposits. It takes into account the distribution of quartz and feldspar within the granulometric spectrum, more precisely by the limiting sizes of fractions in which these minerals accumulate in the course of cryogenesis [Konischev, Rogov, 1994]. This coefficient was called the coefficient of cryogenic contrast (CCC):

$$CCC=Q_1/F_1:Q_2/F_2,$$

where Q1 and F1 are the contents of quartz and feldspar, respectively, in the fraction 0.05-0.01 mm; Q2 and F2 are the contents of quartz and feldspar, respectively, in the fraction 0.1-0.05 mm.

The deposits formed in cryolithozone have the CCC values greater than 1, whereas the deposits formed outside this zone, i.e., under temperate and warm conditions, according to N.M. Strakhov's scheme, have the CCC values less than 1.

Along with the CCC parameter which specifically allows assessing the cryogenic nature of mineral matter of the sediments, it is necessary to use another indicator that can be called the heavy fraction coefficient (HFC) [Konishchev, 1981]:

$$HFC = \Sigma_{HM} 0.05 - 0.01\ mm / \Sigma_{HM}\ 0.1 - 0.05\ mm,$$

where HFC is the heavy fraction coefficient and HM is content of heavy minerals.

HFC is the ratio of the weight content of heavy minerals in the fraction 0.05-0.01 mm to the weight content of heavy minerals in the fraction 0.1-0.05 mm; it characterizes the degree of exposure to the aqueous- or air-sorting process or lack thereof.

The HFC values greater than 1, characteristic of the sedimentogenic distribution of heavy minerals by grain size, indicates the presence of aqueous- or air-sorting. The HFC values less than 1 point to the eluvial origin or the nearest redeposition (slope or proluvial) of cryogenic fine earth.

The use of theses indices in the analysis of the origin of the ice complex in Northern and Central Yakutia, much of which is made up of loess deposits, allowed us to establish the leading role of cryogenic disintegration in the formation of mineral matter of these deposits [Konishchev, 2013]. Different facies-genetic types of loess-like deposits of the ice complex were isolated. These are, first of all, the products of the nearest redeposition of cryogenic eluvium with the corresponding parameters of the proposed indices and the products of redeposition of cryogenic fine earth in various dynamic conditions of the aqueous environment (Fig. 3).

The application of the proposed indices (CCC and HFC) to the analysis of individual sections of soil-loess formations within the Pleistocene periglacial zone of the East European Plain, outside the zone of modern cryogenesis, also yielded interesting and generally positive results [Konishchev et al., 1985].

BASELINE DATA AND RESEARCH RESULTS

The purpose of the paper presented herein is to discuss the application of the method to analysis of the composition of sediments of two sections of loess-soil formations located on the southern margin of the European range of loess deposits (the Beglitsa section) and within the Loess Plateau in China (the Zhaoxian section)

This study was made possible by Professor A.A. Velichko who, together with his colleagues, had invited the authors to take part in an integrated international project. The authors were provided with samples from the above-mentioned sections, which were analyzed using the approach described above.

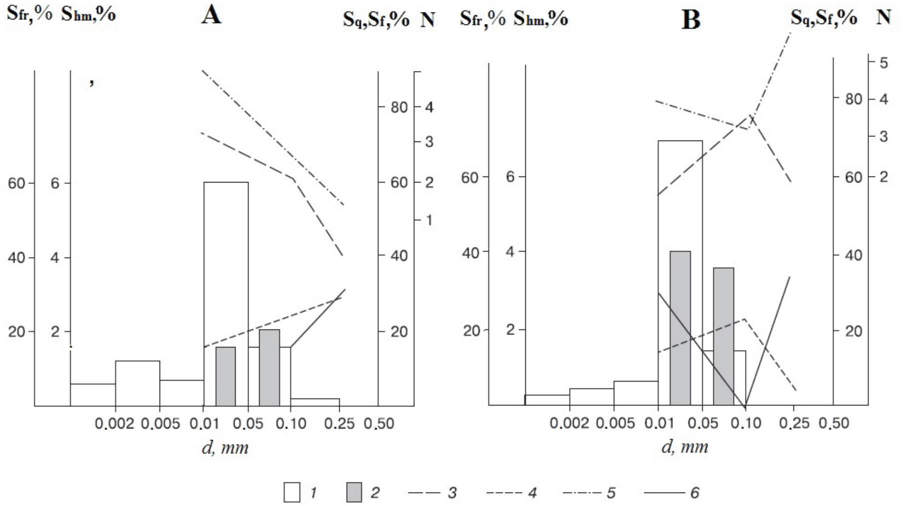


Fig. 3. The relationship between granulometric and mineralogical parameters in the sections of Mus-Khay outcrop of "brown" aleurite (A - depth 4.4 m) and of greenish-gray aleurite (B - depth 19-20 m).

1 - granulometric composition (Sfr,%); 2 - content of heavy fraction (Shm,%); 3 - distribution of quartz content by fractions (Sq,%); 4 - distribution of feldspar content by fractions (Sf,%); 5 - distribution of the quartz/feldspar ratio (N) by fractions; 6 - distribution of rock fragments by fractions (%) [Konishchev, 1981].

The main method of studying the mineralogical composition of the loess samples was X-ray diffraction analysis. The fractions 0.05-0.01 mm and 0.1-0.05 mm were isolated by sieving. The Beglitsa section samples were analyzed by A.N. Kurchatova at the Cryotrasology Laboratory of the RAS Institute of the Earth's Cryosphere with D2 PHASER diffractometer; the Zhaoxian section samples were analyzed by D.G. Shmelev at the Department of Lithology and Marine Geology, Faculty of Geology, Lomonosov Moscow State University, with DRON diffractometer.

The Beglitsa section is located approximately 25 km west of Taganrog on the northern coast of the Gulf of Taganrog, the Azov Sea (Neklinovsky District, Rostov Oblast), on a 3km long steep seashore; the section exposes the so-called Beglitskaya terrace soils. The coordinates of the section are N47°07', E38°30' The maximum height of the cliff at the site where the section is located is 17.8m, and the average height is about 16-17m a.s.l. The section exposes the Late Valday loess with the horizons of the buried soils of the Bryansk and Mezinsky pedocomplexes; the lower part of the section is composed of the liman-alluvial Late-Khazarian deposits.

Nine samples from the Beglitsa section were analyzed; these samples were uniformly distributed within the section (Fig. 4, A). Some of the samples were taken from the loess while others were taken from the sediments of the pedocomplex. In all loess samples, the CCC values were greater than 1 and the HFC values were less than 1, thus pointing to a non-sedimentary nature. Therefore, mineral matter of the loess horizons is generally a typical cryogenic fine earth.

The results may be interpreted in more detail using the relationship between the CCC and the average annual temperature of the soil surface obtained earlier by one of the authors [Konishchev, 1999] (Fig. 5). The highest CCC value (1.36) is associated with the Late Valday loess horizon above the Bryansk soil. This allows us to assume the existence of shallow high-temperature permafrost during that period. A lower CCC value (1.13) associated

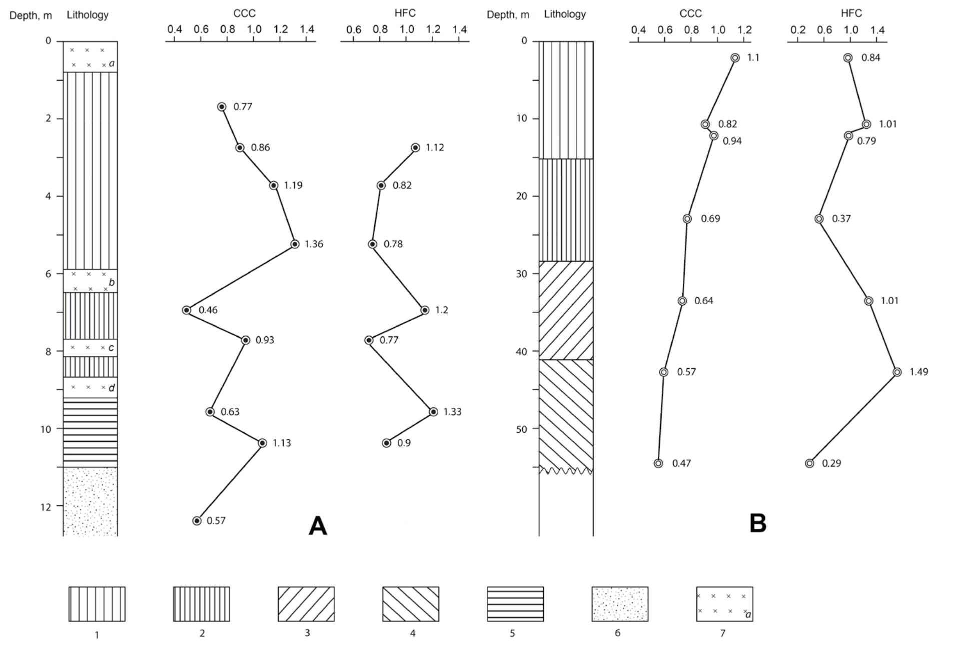


Fig. 4. Distribution of the CCC and HFC values in the Beglitsa (A) and Zhaoxian (B) sections.

1 - pale-gray loess, 2 - light-pale loess, 3 - gray-yellow loess, 4 - yellow-brown loess, 5 - gray-brown loess-like sandy loam, 6 - silty sand, 7 - soil horizons: a-modern soil, b - Bryansk paleo-soil, c - Mezinsky paleo-soil, Krutitsky horizon, d - Mezinsky paleo-soil, Salynsky horizon

with the period of formation of the Middle Valday loess, suggests a possible existence of island permafrost in this region. The samples taken from the soil and underlying horizons do not manifest the cryogenic nature of mineral matter. Obviously, this is the result of the effect of soil processes on the initially-cryogenic distribution of the mineral parameters within the granulometric spectrum characteristic of typical loess.

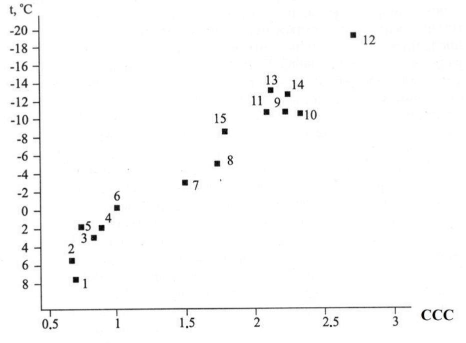


Fig. 5. The relationship between CCC and the average annual soil temperature at a depth of 40-50 cm.

1 - podzolic soil on glaciolacustrine sediments (Belarus, near Minsk); 2 - podzolic loam soil on moraine (Belarus, Poozerye); 3 - sod podzolic and podzolic loam soil on cover loam (the Klinsko- Dmitrovsky Ridge, southern taiga); 4 - podzolic loam soil on cover loam (middle taiga, near Syktyvkar); 5 - podzolic loam soil on cover loam (Western Siberia, settlement Laryk); 6 - gley-podzolic soil on cover loam (northern taiga, Troitsko-Pechorsk); 7 - peat-gley soil on cover loam (southern tundra, settlement Vorgashor); 8 – peat-gley oil on cover loam (Bolshezemelskaya tundra, near Vorkuta); 9 - loamy eluvium sandstones and shales (the Yano-Omoloy interfluve, the Kular Ridge); 10 - tundra gley soil on the ice complex sediments (the Indigirka River, near Vorontsov Yar); 11 - tundra gley soil on the ice complex sediments (the coast of the East Siberian Sea, the Chukchi Peninsula), 12 – eluvial-solifluction deposits (Pamir, elevation 6 200 m, the edge of a firn plateau); 13 - eluvium of sandy-argillaceous shale (the East Siberian Sea, the Svyatoy Nos Peninsula); 14 - eluvium of sandy-argillaceous shale (the East Siberian Sea, the Shirokostan Peninsula); 15 - eluvium of sandy-argillaceous shale (low reaches of the Kolyma River).

In the lowest sand sample associated with the transition layer of liman-alluvial sediments, the CCC value is 0.57, which indicates that these deposits were formed under a rather warm climate.

Thus, the data on the composition of the loess horizons in the Beglitsa section allow us to interpret them as products of cryogenic transformation of the original rocks (most likely, these are liman-alluvial deposits of the Khazar transgression) that were redeposited in depressions of the multiple terraced delta. At the subaerial stage of the territory development, the relief leveled out and all surface irregularities of the liman deposits were buried under the subaerial layer of the soil-loess sequence. This conclusion is also supported by a geological profile along the southeastern coastline of the Gulf of Taganrog and the mouth of the Don River [Putevoditel..., 2013].

The second studied section, Zhaoxian, is located 50 km of Jinyuan, Gansu province, in the middle reaches of the Huang He River. The coordinates of the section are N36°24', E104°36'. The section outcrops in the slope of a 30° steep clough. In the lower part of the slope, there is a well-defined terrace-like bench. The total depth from the plateau surface to the bed is 300 m. The section has a sufficiently homogeneous, 55 m thick, loess layer. The section deposits include pale gray loess, sometimes with a brown tint, a whitish powder of carbonates along fine root traces, occasionally with brown streaks and spots. The granulometric composition is very homogeneous over the whole studied stratum and is composed of coarse aleurite. Soils in this section are absent for large intervals; only at depths of 11.5, 34.5, and 43.5 m, there are some signs of soil processes: reddish-brown and brown color and manganese patches. In this respect, this section is very similar to the section of the "last glacial" [Zykina, Zykin, 2012] loess that does not contain soils and is located in the northern part of the Chinese Loess Plateau. Seven samples from depths of 3-55 m of this section were analyzed (Fig. 4, B).

The CCC values shown in Fig. 4 (B) are distributed quite consistently with depth – from 1.1 at 3 m to 0.47 at 55 m. Based on the relationship between the CCC values and the average annual temperature of the soil surface (Fig. 5), it can be asserted that the CCC value of 1.1 corresponds to the existence of island cryolithozone; the CCC values from 0.9 to 0.6 point to conditions of deep seasonal freezing, and even lower CCC values point to that the depth of seasonal freezing was only 0.7-0.8 m.

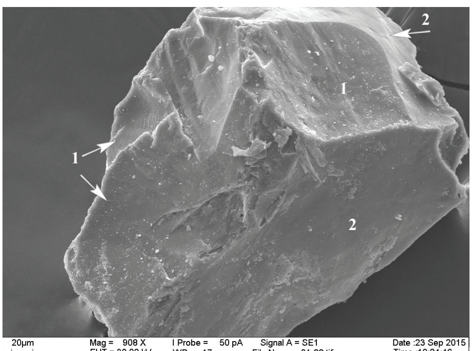
The HFC values are also very indicative. In the uppermost sample, where CCC is above 1, which suggests a certain role of cryogenesis processes in the formation of dispersive properties of the deposits of this horizon, a non-sedimentogenic distribution of the heavy fraction within the granulometric spectrum is observed. This is an additional argument in favor of the cryogenic nature of mineral matter in this sample. In a number of other samples (12 m, 23 m, and 55 m), a non-sedimentogenic distribution of heavy fraction minerals is also observed, which does not agree with the determining role of the eolian genesis of the deposits at these depths. In samples taken from depths of 11.5, 34.5, and 43.5 m, where some signs of soil processes were noted, the HFC values, on the other hand, were greater than 1. Therefore, probably during the accumulation of sediments at these depths, processes altering the cryogenic distribution of heavy fraction minerals within the granulometric spectrum were in play.

This section clearly indicates that cryogenic fine earth can accumulate not only in the cryolithozone environment and in the layer of seasonal thawing, but also under the influence of seasonal freezing; this fine earth serves as the source of the formation of rather thick loess strata (with the nearest redeposition).

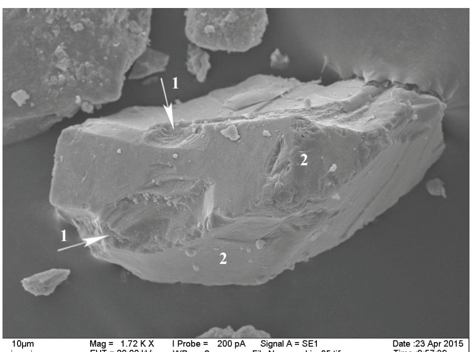
The validity of the conclusions presented in this paper is based on a rather limited number of samples, which implies the need to expand the scope of the study.

Nevertheless, it is quite obvious that cryogenic factors played a very important role in the formation of the analyzed section of the Zhaoxian loess stratum. In this case, the influence of eolian sedimentation cannot be completely excluded, although its significance, in any case, was not decisive; thus, the question on the sources of mineral matter arises. If these were not primarily eolian accumulations, as was suggested in many publications [Zykina, Zykin, 2012], it is important to note that the Loess Plateau, despite its fairly large size, is located not so far away from the alimentation zone. Precisely it could be this source during the last glacial maximum, when, through a system of valleys dissecting and draining mountain structures, huge masses of disintegrating rock material entered the river valleys and were deposited on the slopes, forming accumulative surfaces such as the Loess Plateau.

The manifestations of cryogenesis in the samples of the studied sections were also noticeable at the morphological level. The sand fractions particles (1-0.5 and 0.5-0.25 mm) were investigated with the LEO 1240 scanning



A



B

Fig. 6. Morphology of the loess sandy fractions particles of the Beglitsa section (5.2 m deep) (A) and the Zhaoxian section (3 m deep) (B).

1 - fresh conchoidal cryogenic shear surface;

2 –patches of smooth polished and micro-pitted (eolian) surface.

electron microscope. The form and the surface of the particles in samples with high CCC values had features indicative of the cryogenic action (Fig. 6). These include an angular shape, shears, and fractures, which are very similar to those in the sediments of the modern active layer of the regions of Canada, Spitsbergen, and Mongolia [Woronko, Pisarska-Jamrozy, 2015].

CONCLUSIONS

The analysis of the samples from the two loess sections demonstrated the validity of the cryolithological method in studies of mineral matter. The authors have shown a significant, if not decisive, role of cryogenic factors in the formation of the composition of the loess horizons of soil-loess sequences. This is particularly clearly seen in the example of the Beglitsa section. The potential of cryolithological analysis of the Loess Plateau loess is also evident in the example of the Zhaoxian section. Without denying the role of the eolian mechanism in the formation of loess horizons of soil-loess formations, the analysis of the studied samples proved that not only within the periglacial permafrost zone, but also under conditions of seasonal freezing in the Pleistocene, processes of cryogenic transformation of deposits were active, which contributed to the formation of composition and properties of the sufficiently thick loess layer.

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ASSESSMENT OF GROUNDWATER RESPONSE AND SOIL MOISTURE FLUCTUATIONS IN THE MUGELLO BASIN (CENTRAL ITALY)

ABSTRACT. Extreme meteorological events such as heavy rainstorms are considered to increase due to global warming. The consequences of such events can be manifold, and might cause massive interferences of the hydrological system of a landscape. Particularly the intramontane basins of the Apennine in Italy are frequently threatened by extreme rainfall events that cause severe damage on buildings and infrastructure. Moreover, the lithological and geomorphological settings of these basins, which depict the products of a complex landscape history, amplify these threats. In order to develop possible mitigation strategies, it is crucial to assess landscape functioning by analysing hydrological processes of the landscape system. In this study, we conducted spatially distributed and dynamic hydrological modelling on a catchment in the intramontane basin of the Mugello valley in Tuscany, Italy. Foremost, measurements of saturated hydraulic conductivity and texture analyses were performed to estimate both infiltration and hydraulic conductivity of the surface and topsoil, respectively. We regionalised the collected data with a stochastic gradient treeboost method for the whole catchment. Soil depth was estimated with a simple sine-cosine-slope relation, whereas, hydropedologic parameters for the hydrological model were estimated with pedotransfer-functions applied on the collected infiltration data. We modelled a period of 100 days, representing each day per time step. A synthetic rainfall period was compiled based on measured data from meteorological stations within the Mugello basin. To produce a reliable synthetic rainfall data set, the estimated precipitation values were set in comparison to calculated return periods for extreme events of all available meteorological station. To assess the diversity of the hydrological response of several locations in the catchment, six semi-random test locations were located on hillslopes and spots were sedimentation is apparent. The results show that groundwater and soil moisture fluctuations appear to be significantly different for both hillslopes and areas were sediments are deposited. The differences cannot be explained by the topographical settings but rather by the approximated thickness of the weathered zone and the spatial diversity of the hydropedological properties of the soil.

KEYWORDS: geographical hydrology; STARWARS/Probstab; groundwater; soil moisture; lacustrine sediments; Mugello;

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INTRODUCTION

Global warming has severe effects of changes in annual precipitation values and the frequency and intensity of extreme events [Crisci et al. 2002]. Italy, and in particular the Apennine, is threatened by extreme rainstorms and their diverse impacts on the landscape. The hydrological processes and imbalances that can be triggered by extreme rainfall events appear to be very complex. Several studies have been conducted to analyse the hydrological effects of certain rainfall events on Mediterranean landscapes [Brath et al., 2006; Brath et al., 2004; Montanari & Toth, 2007]. Spatially-distributed hydrological models such as TOPMODEL [Beven & Kirkby, 1979] or WEPP [Nearing et al., 1989] are able to assess and predict hydrological responses of landscapes to rainstorms. Several studies successfully applied similar hydrological models for study sites in the Mediterranean to show the hydrological impact of rainstorms and the triggered sediment dynamics [Crisci et al., 2002; Brath et al., 2006; Brath et al., 2004; Montanari & Koutsoyiannis, 2012]. The Mugello basin in Tuscany is of highly interest considering its landscape evolution and the geomorphological processes. The diverse lithological and geomorphological setting as well as land cover changes and anthropogenic impacts combined with frequent extreme rainstorms or long precipitation periods let the Mugello being an example for the major geomorphological challenges man has to face in times of global warming.

In this study, we assess the hydrological response of some small Torrents, tributaries of the Sieve River draining the Mugello basin. Hereto, data on saturated hydraulic conductivity, pedologic and climatic conditions were collected to conduct basic hydrological modelling. A particular focus was set on the hydrological response of the catchment after a heavy rainfall period that typically can occur in spring and autumn. Therefore, we produced synthetic rainfall data of a representative rainstorm event that are based on rainfall data from meteorological stations within the Mugello basin. Saturated hydraulic conductivity and infiltration were measured to estimate the infiltration capacity of the topsoil and thus to predict when the soil column becomes saturated and runoff or subsurface flow along a lithic boundary can occur. Rainfall and hydraulic conductivity data were used as input information for a physically based water response model. The results reveal insights in the dynamics of the hydrological regime and the potentials of the related sediment fluxes. This information is expected to provide better knowledge about groundwater fluctuations and surface runoff during rainstorms that are typical for the region.

STUDY AREA

The Mugello, a typical Intra-Apennine basin with an area of about 20 km^2, is located approximately 30 km north of Florence, Tuscany, Italy (Fig. 1). The intermontane basin is drained by the river Sieve, a left tributary of the Arno river [Garfagnoli et al., 2013]. Our study area is a small hydrological catchment in the northwestern part of the Mugello within the administrative borders of Barberino di Mugello and Scarperia as well as San Piero. The most prominent town within the site is Barberino di Mugello close to the autostrada A1 that passes through the western part of the basin. The studied catchment has a size of ~ 6.7 km^2 and is drained by several torrents to the South into the Lago di Bilancino or directly into the Sieve river, respectively. These are from West to East: Torrente Calecchia, Torrente Sorcella, Torrente Travaiano, and Torrente Anguidola. Since the town of Galliano is located in the centre of our study area, the investigated catchment that contains all the torrents mentioned is named 'Galliano catchment' throughout the whole paper.

1997]. According to Vai [2001] the Mugello developed throughout the Tertiary in a continental collisional setting. The Galliano catchment consists of calcareous claystones partly interrupted by Ligurid limestones and serpentinites that tectonically overly early-middle Miocene sandstones and siltstones [Benvenuti & Martini, 2002]. Benvenuti & Papini [1997] distinguished two phases of infilling: a fluvio-lacustrine phase (approx. late Pliocene to early Pleistocene) and an alluvial phase (approx. early Pleistocene to Holocene). During the fluvio-lacustrine

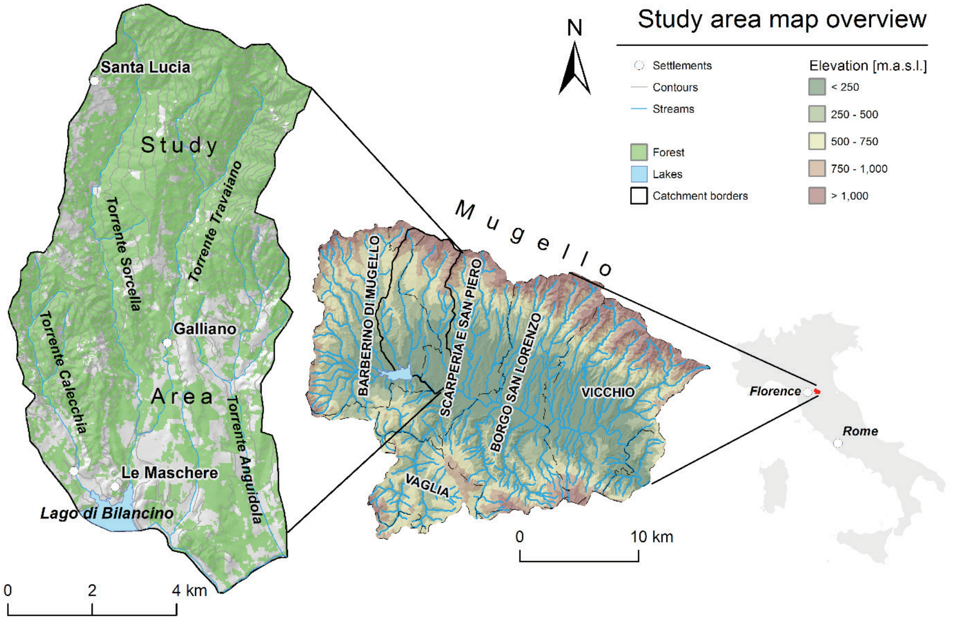

Fig. 1. Study area within the Mugello basin.

The lithological setting was described by former studies that were based on extensive field mapping and sedimentological analyses [Benvenuti 1994, 1997; Benvenuti & Papini, 1997; Sanesi, 1965]. The geology of the area contains mainly alluvial-lacustrine deposits of the Pliocene and Upper Pleistocene which is typical for comparable intramontane (or periphel, after Martini& Sagri, 1993] basins of the Northern Apennine. Studies that provided structural and stratigraphic data in the 1990s suggest that the Mugello basin formed by alternating tectonic compression and crustal extension [Benvenuti, 2003; Boccaletti et al.,

phase, the basin was filled up to 100 m with peat and silty clay indicating a palustrine environment, particularly in the western part of the basin. The alluvial phase, however, can be subdivided in three major periods of base-level fall, leading distinctively to terracing of the fluvio-lacustrine and alluvial sediments [Sanesi, 1965].

Most of the soils in the Scarperia area and surroundings originate from silty-clayey sediments [Zanchi, 1988] and thus contain high amounts of clay minerals. However, the fluvio-lacustrine bed-material mostly consists of layers of packed and loose gravels as well as silty-sand layers with respectively low amount of clay. These sediments are prevalent in streambanks that are particularly affected by undercutting of the Sieve River [Rinaldi & Casagli, 1999]. Intense erosional and mass wasting processes such as sheet erosion and landslides threaten the slopes at the margins of the Mugello basin.

The study area is agriculturally used, particularly the valley bottoms. Mainly annual crops such as grain maize, barley and durum wheat are cultivated. On the sloping areas above the lacustrine sediments also olive groves, orchards and vineyards occur [Benvenuti, 2003; Piorr et al., 2009]. Forests are primarily located on higher altitude at the ridges of the basins margins. The valley itself was highly affected by anthropogenic induced land use changes. Valuable contributions on human-landscape relations and anthropogenic impacts on the land cover were conducted by [Rinaldi & Rodolfi, 1995]. Agricultural activity of man can be dated back before 1600 A.D. with starting bank adjustments of the channel. From 1600 to 1900 A.D. a progressive uncontrolled deforestation started combined with intense aggradation in the inter-embankment zones of the Sieve River [Rinaldi & Casagli, 1999]. Reforestation and upland sediment retention started after 1900 A.D. [Rinaldi& Casagli, 1999; Rinaldi & Rodolfi, 1995].

Climate is Mediterranean with an annual precipitation reaching from 890 mm near San Piero a Sieve (211 m. a. s. l.) and 1300 mm at Monte di Fo' (820 m a. s. l.), due to orography. The monthly maximum in Borgo San Lorenzo is about 120 mm in November, while the minimum is about 20 mm in July. Annual mean temperature is about 14 °C. The monthly maximum in July and August reaches 23.5 °C and the minimum is about 5 °C in January. The mean annual temperature at Monte di Fo' is about 11 °C.Daily precipitation amounts with a return period of 1 year reach from 35 mm at S. Piero a Sieve to 50 mm at Monte di Fo'. 5 year events range from 60 mm to 90 mm and 50 year events from 90 mm to 150 mm (Fig. 2). Values of the other meteorological stations close to the study area are show the same range. The upper parts of the catchments are affected by stronger events than the lower

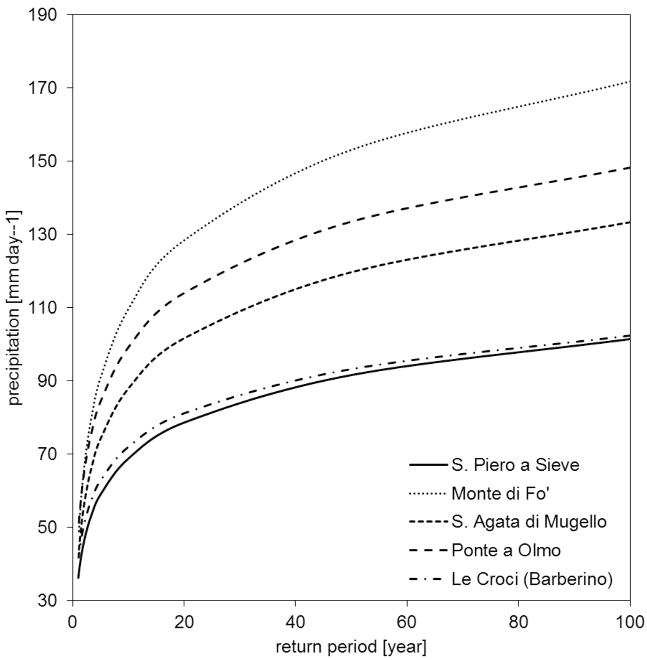

Fig. 2. Interpolated (1-10 year) and extrapolated (11-100 year) extreme precipitation events, based on data by SIR (2014).

areas. The highest amount between 1992 and 2013 with 121.5 mm was reported on 8th of August 1997 at S. Piero a Sieve (five centennial event; SIR 2014).

MATERIAL AND METHODS

Hydropedologic measurements and soil identification

Saturated hydraulic conductivity was measured at 70 locations in the lower part of the Galliano catchment. We used both IL-2700 Hood-Infiltrometer [Umwelt Gerätetechnik GmbH] and a constant head permeameter [Amoozemeter, Ksat Ltd, Amoozegar, 1989]. Infiltration rate was measured with the IL-2700 under saturated conditions or 0-tension respectively, to provide a better comparability with the Ksat values of the Amoozemeter. Ksat was measured in the topsoil (< 25 cm) (Fig. 3).

We applied a stochastic approach based on logistic regression technique [Atkinson et al. 1998] using the measured Ksat values and as dependent variable and environmental predictor variables delineated from the DEM such as slope and elevation following [Reuter et al. 2009]as independent variable.

The dataset was split in train (80% of Ntot) and test data (20% of Ntot). Hence, the model was calibrated with the train data and validated with the test data. We evaluated the performance of the model using the receiver operator characteristic (ROC) curve for training and test data. According to(Lemeshow & Hosmer, 1982], AUC values exceeding 0.62 indicate acceptable predictions.

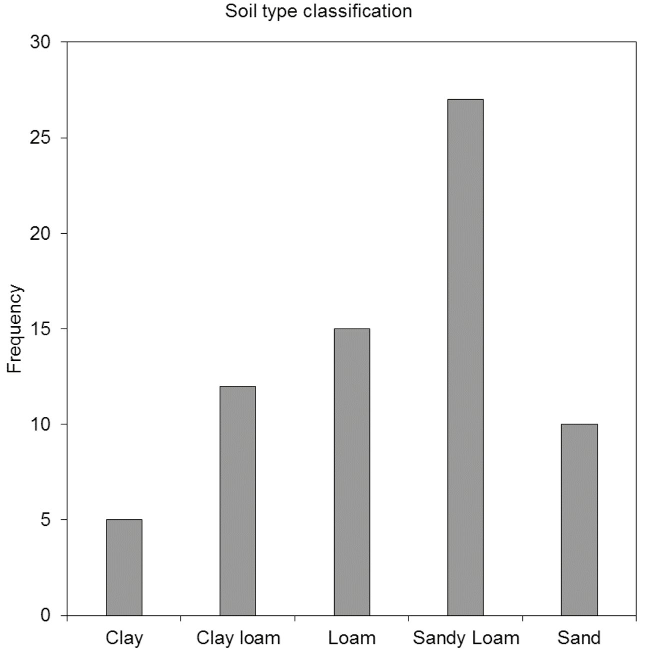

Fig. 3. Soil texture classification obtained from soil profiles and Ksat values of the sampled locations.

For the preparation of the hydrological input parameter (cf. chapter 3.3) pedotransfer functions were used to gather information about the soil layers > 25 cm. Therefore, we conducted soil type classifications with finger test for texture approximation on six soil profiles. The soil texture information were then implemented in pedotransfer relations according to Saxton et al. [1986] and Saxton & Rawls [2006]. The application of these relations yield information about pedohydrologic properties, such as volumetric moisture contents or matric suctions, in depths > 25 cm where ksat values are unknown.

DATA PREPARATION AND MODELLING

We predicted soil depth with a basic sine-cosine relation based on the slope angle, given by the equation:

$$z = -\frac{0.5}{COs(\beta)} * In(\sin(\beta))$$

where β is the slope angle in degree and 0.5 is a constant obtained from empirical observations[Pelletier & Rasmussen 2009].
A basic implication of the sophisticated and spatially-distributed hydrological model STARWARS [Van Beek, 2002] was used to predict both groundwater fluctuations and volumetric moisture content of the weathered load. Permeability of the lithic boundary was chosen according to the information of the lithological underground obtained from [Benvenuti, 2003].

Based on the regionalised ksat values, we used the approach of [Wösten et al., 1995] to estimate spatially distributed soil texture information. Consequently, the required soil parameters for the model were compiled with relations of pedotransfer functions, presented in Saxton & Rawls [2006] and Saxton et al. [1986]. In this regard, we calculated saturated moisture content, residual volumetric moisture content, air entry value, shape factor, dry bulk density and soil cohesion. The initial groundwater level as well as the volumetric moisture content of the soil column was set to 0.

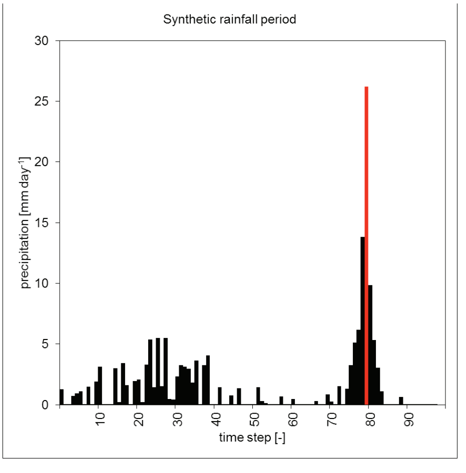

Fig. 4. Distribution of rainfall over the modelled period. The red bar shows an extreme event during the rainfall period at day 79.

Since continuous daily rainfall data were not available for our study area, synthetic precipitation values were created based on information about heavy rainstorms events that were recorded from meteorological stations from Borgo San Lorenzo and San Piero a Sieve (Fig. 4). The model was run for 100 time steps with each step representing one day.

RESULTS

In context of geographical hydrology, we define soil as the entire weathered material to the contact of a lithic boundary or the bed-

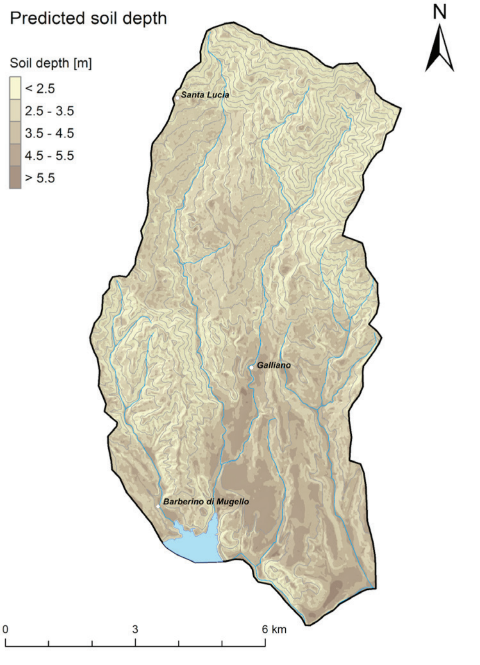

Fig. 5. Predicted soil depth for the Galliano catchment.

material, respectively. Most of the flat areas are located within the basin, where the corpus of the fluvio-lacustrine sediments is accumulated. Claystone, sandstone and partly marls with limestone lenses underlie the margins and hillslope environments. In this regard, it has to be considered that the weathered material is shallower and the distance to the lithic boundary is rather short. The results of our

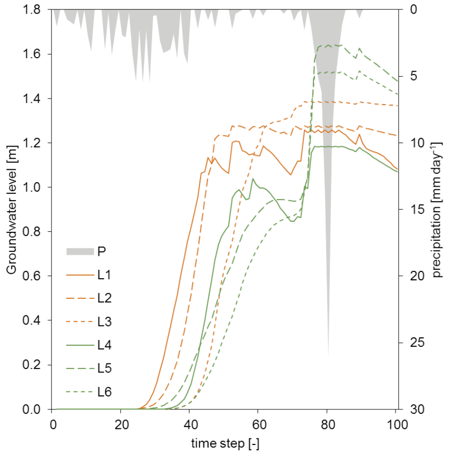

Fig. 6. Groundwater level response to rainfall (grey area; P) during the modelled period for six locations (L) within the catchment. Locations 1-3 (red lines) are located at the valley bottom. Locations 4-6 (green lines) are located on slopes (cf. Fig. 7).

soil depth approximation (Fig. 5) replicate the lithological conditions and the expected thickness of the soil mantle sufficiently for a proper hydrological modelling procedure.

Hydrological response and soil water fluctuations

The predicted groundwater level considerably increases between time steps 23 (L1 and L2) and 26 (L5 and L6) when daily rainfall frequently exceeds values of > 3.5 mm per day (Fig. 6). After a rapid increase to

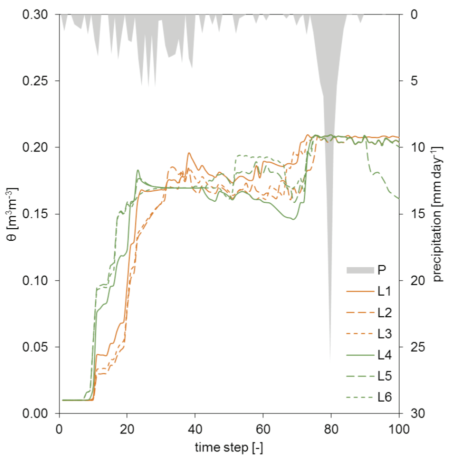

Fig. 7. Volumetric moisture content of soil columns at locations 1-6.

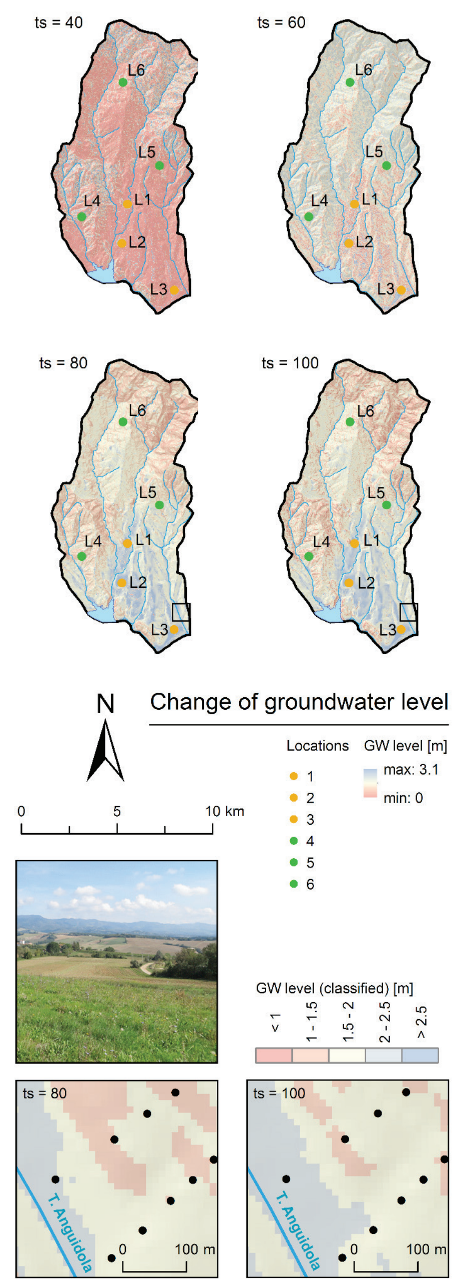

Fig. 8. Groundwater (GW) fluctuations for time steps 40, 60, 80 and 100.
The small figures show an investigated slope section (black dots: sample positions) and its groundwater level changes for time steps 80 and 100. We chose a classified colouring to show changes in the groundwater level for this location. The image illustrates the landscape setting of this slope section.

values between 0.9 m and 1.3 m locations 2, 3, 5 and 6 show equilibrium conditions, whereas groundwater level at positions L1 and L4drop to 1.1 or 0.8 at time step 69, respectively. All locations that are situated in rather flat areas at the valley bottom (L1-3) do not show response to incipient water input from the rainstorm at time step 69. In contrast, locations situated on hillslopes (L4-6) show all rather quick response, followed by a decline after time step 83.

Fig. 7 shows the changes in volumetric moisture contents (θ) for the locations L1-6. Moisture contents increase at all locations between time steps 8 and 11. L 4-6 show a rapid rise of moisture content after rainfall initiation up to 15 % or 18 % respectively between time steps 18 and 21. This rapid increase is followed by a stagnation and steady decrease until the end of the first rain period. L1-3 shows a delayed response of increase in moisture content to 17 % (L2) up to 19% (L1). The curves show swaying between time steps 30 to 70, followed by an increase up to 21 % coinciding with the rainstorm event.

DISCUSSION

The results shown in Fig. 6-8 indicate that locations on hillslopes do have quicker response to water input than those located in flat areas. This might be due to two reasons: First of all, soil thickness is presumably lower than in flat areas. Interflow within the soil column and runoff along the lithic contact can occur faster and more rapid. However, groundwater level rises rapidly when water reaches the lithic boundary and percolation through the soil column exceeds the infiltration capacity into the bed-material. In this regard, discharge along the lithic boundary has to be less than the amount of percolating water from above and the loss of infiltrated water into the bed-material. This considerably occurs, when the bedrock is rather impermeable, as it is the case for the slopes in our study area. Interestingly, the model results of the predicted water table in flat locations (L1-3) show equilibrium conditions with a decline after the heavy rainstorm between time steps 69-83 (Fig. 6). This might be explained by the fact that infiltrating water and water from the upstream areas balance the loss of water into the bed-material. In this regard, we presume that the rather coarse textures of the lacustrine sediments highly contribute to a desiccation of the overlaying soils.

The decent increase of volumetric soil moisture content of soils on slopes might be due to lower predicted soil depth at steeper locations and a faster recharge velocity than it could occur in deeper soils (Fig. 7). The steady decrease after reaching a local maximum of 15 % (L5) to 18 % (L 4) indicates that water has reached the lithic zone. Thus, percolation stops and water flow along the lithic contact can occur. However, this parameter depicts a very vague point of the model, since hydraulic conductivity of the bed material has been approximated. On the other hand, the lithological setting (e.g. calcareous claystone on slopes) could provide equilibrium conditions due to infiltration into the bed-material. L4-6 are located in hillslope environments, underlain by calcareous claystone as it was reported by Benvenuti [2003]. Consequently, infiltration into the bed-material is significantly reduced, which would promote the formation of an aquifer layer when deeper soil layers get close to saturation. However, it is more likely that the gentle decline of moisture content between time steps ~ 20 to ~ 70 at L4-6 is due to interflow loss of the soil column rather than to infiltration into the bed-material, since we set infiltration capacity of the lithic contact to zero at hillslope locations. Moreover, it is observable that the soil column does not reach saturated conditions between time steps 20 to 70. Saturation, however, is clearly apparent with beginning of the heavy rainfall period at time step 69. For all locations on slope positions, the soil reaches the maximum of saturated volumetric moisture content (~ 20 % - 21 %).

In contrast, locations 1 to 3 show a different response to the rainfall input. The delayed increase of moisture content compared to L4-6 is directly related to the deeper soils and thus, the higher potential of water retention. Fluctuations of soil moisture that can be observed between times steps 30 to 70 are most likely due to equilibrium conditions of infiltrating water from the surface into the soil and percolation from the soil into the bed-material. We considered the lithic boundary as not sealed and permeable to reproduce the hydropedologic conditions and granular structures of the lacustrine bed material. However, time steps 30 to 70 may be distinguished into two parts: a) the first part depicts the rainfall period from time steps 30 to ~ 38 where still infiltration conditions are existent; b) a dry period represented by time steps ~ 38 to ~ 68 where no rainfall input occurs.

Nevertheless, soil moisture fluctuations are comparable for both of the parts and do not change significantly. This relation indicates an input of interflow or runoff water from surrounding slopes and the catchment margins. This appears to be reliable because L1-3 are located on the less-inclined valley bottoms with higher specific catchment areas. Comparable to the locations on the slopes, L1-3 show an increase of volumetric moisture content with the beginning rainstorm event at time step 69 and reach their maximum of ~ 20 % - 21 %. In contrast to some of the locations on the slope (e.g. L5), infiltrated water does not exit the soil column and might reduce a drop of soil moisture, but stays constantly saturated. Interestingly, the findings report only a drop of soil moisture content at L5, which could be explained that the upslope area that contributes to water inflow into L5 is rather small. Thus, outflow might exceed inflow and thus a quicker reaction in soil moisture content.

The hydrological response of the soils tested in our model are in large part in line with observations of former studies[e.g. Garfagnoli et al., 2013]. The model results reveal a high absorption potential of the clayey soils during a long but moderate rainfall period (e.g. modelled time steps 0 to 40). This is due to the reduced infiltration capacity of the clayey soil and the respectively high thickness of the drainable soil mantle. Garfagnoli et al. [2013] also reported the relationships of thick clayey soils and their reduced infiltration and percolation capacity. Thus, the model output appear reliable considering dry soil conditions and a water absorption period of approx. 40 days until the soil column becomes nearly saturated. However, the results should be regarded as theoretical for several reasons:

1) even after dry season it remains doubtful whether the soil is fully parched. Thus, a residual volumetric moisture content would cause faster responses in water level changes and groundwater fluctuations.

2) Perched groundwater conditions due to structural diversity of soil texture within the soil mantle are not considered.

3) Hydrological parameters of the lithic contact zone or the lacustrine sediments that are underlying the soil were roughly estimated according to facies descriptions of Benvenuti [2003]. Water storage capacity and conditions of the aquifer layers are very difficult to establish and hence, our model input based on the above described hypothesis and derivation methods remain a first estimate.

A major critical point of the model output is the typical condition of Mediterranean clayey soils after a dry season. Cracks within the soil column can develop, when the soil moisture content drops dramatically during the dry season. Dilative, swellable or active clays such as Montmorillonite or Illite can cause these cracks under dry conditions. Garfagnoli et al. [2013) reported high ratios of clays in general (~ 51.02 %) and active clays in particular (~ 21.62 % Montmorillonite, ~ 27.65 % Illite). Hence, infiltration and percolation rates are massively increased. Under such conditions, it is expected that infiltrating water percolates much faster into deeper soil layers and cause much faster an increase of the groundwater level.

CONCLUSION AND OUTLOOK

In this study, we presented a first assessment of groundwater response and soil moisture fluctuations of a catchment of the Mugello basin in Tuscany during a synthetic rainfall period. Therefore, we applied a spatially-distributed and dynamic hydrological model. Hydropedologic parameters were obtained from in-field measurements of saturated hydraulic conductivity and soil texture. The results show that the rise of groundwater level is quite diverse comparing hillslope positions and sedimentation types. The same findings were observed for the changes in volumetric moisture content (θ) that is explained by the diverse lithological underground and the associated differences of soil properties. Moreover, the results show challenges and drawbacks of hydrological modelling in a landscape, where soils are partly separated from the underlying bed-material by a quite permeable lithic boundary and a respective high content of swelling clays is apparent. However, reliable and validated information about the landscape hydrology are fundamental for further analyses on sediment dynamics and related hydropedologic processes such as gravitative mass movements. Therefore, our results highlight the difficulties that are connected to hydrological modelling approaches in areas with a high variability in climatological and lithological conditions.

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RECENT CHANGES OF ANNUAL FLOW DISTRIBUTION OF THE VOLGA BASIN RIVERS

ABSTRACT. Modern features of the annual flow distribution of the Volga Basin were analyzed. Statistical analysis of the annual flow data for the spring, summer-autumn, and winter seasons were carried out to study the changes of the water regime of the Volga Basin Rivers in 1946–2010, 1946–1977, and 1978–2010 observation years. Using the data of 207 stations, new maps of seasonal flow were created and changes in the natural river flow regulation were shown. In recent decades, the water regime of the rivers in European Russia and their annual flow distribution has changed greatly.
A statistically significant decrease in the river flow irregularity after 1946 has been revealed for the most of the Volga Basin Rivers. It resulted in the increase in the natural regulation index φ, change of the seasonal flow, primarily in low-water period, and especially in winter. The increase in the φ index during the last 30 years is approximately 30%, compared to the similar previous period. Such a change of the φ value took place due to the reduction of the spring flood flow and the increased significance of the groundwater flow.
In the second half of the 1970s, the rivers of the Volga Basin were characterized as "snow-feeding"; at the end of the XXth century, they became the rivers with "mixed feeding" or even "mixed feeding with prevailing groundwater feeding" according to B.D. Zaikov's river classification. This has resulted in the significant increase in the natural flow regulation comparable to the effect of seasonal storage reservoirs.

KEYWORDS: river flow distribution, climate change, seasonal river flow.

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INTRODUCTION

The study of rivers' flow distribution is an important scientific and practical problem in the field of economically effective and ecologically safe water management. A range of issues, relating to this subject, is of interest both from the scientific knowledge view and for a variety of applications. On the one hand, this statement finds ample evidence in fundamental hydrological investigations creating a theoretical basis for the further activity in this area [for example, Andreyanov, 1960; Yevstigneev, 1990 et al.]; on the other hand – in the regulation documents specifying strict calculation algorithms of the annual flow distribution for further application in different fields of economy [SP 33-101-2003, 2004]. Water management options, such as a guaranteed water return, power generation, and controlled storage of annual flow variability, often arise in ecological management of small and medium-size rivers and optimization of the usage of their water resources. The water resources management system also needs to be adapted to seasonal flow variations under climate change. The most recent comprehensive studies were carried out in Russia in the early 1970s when "Surface water resources of the USSR" was published. Since that time, the annual flow regime of the European rivers of Russia has changed significantly making the development of new correlations and calculation models and the creation of modern maps of seasonal flow distribution are the urgent scientific tasks. The purpose of this work is to study modern annual flow distribution of the rivers of the Volga River basin and to calculate new characteristics of their seasonal flow.

BACKGROUND INFORMATION

The Volga River basin is one of the key points to understanding river runoff transformation on the European part of Russia. The basin is influenced by spatiotemporal variation of flow closely connected with natural and anthropogenic factors [Georgiadi et al., 2016]. In this paper, natural component of flow was calculated by empirical correlation with the flow of the non-transformed watersheds. It appears that during the XXth century, a few phases of high and low flow occurred. These phases are well visible in seasonal flow dynamics, while they are washed out in annual flow. The difference between annual flow of Volga and Don Rivers and mean average for the period of observation is now more then 10%. Until the 1970s-1980s, the phase of higher flow was observed. Spring flood runoff increased by 10%, winter low flow – by 50%, and summer-autumn flow – by 25%. According to Georgiadi A.G., Milyukova I.P. [2006)], based on scenarios calculation, in the XXI, increase in both annual and spring flood runoff can bee expected. More detailed analyses were done in the further publication of the authors [Georgiadi et al., 2016]. It was shown that expected changes in the Volga and Don annual river runoff and its intra-annual distribution in the first third of this century can be relatively small, while changes in water use characteristics may be extremely negative in some scenarios, especially in the Don River basin.

The questions of risk management and floods disaster management due to the climate change are variously discussed in the CABRI – Volga reports [http://www.cabri-volga.org/publications.html]. Estimation of the river annual flow distribution is strictly regulated and performed according to a number of standardized documents [SP 33-101-2003, etc.]. The main technique of summarizing data on river flow distribution is identification of regional patterns of seasonal distribution in high, low, and medium water flow years. Seasonal flow distribution is expressed in proportions of annual and seasonal flow distribution – in proportions of the appropriate season flow. In this paper, the estimation of annual flow distribution is performed using the average flow distribution in high, low, and medium water flow years.

Initially, the idea of water regime transformation (the main types and geographic movement of their borders) was expressed in general by Georgievskiy [Georgievskiy et al., 1996]. In the electronic issue [Main hydrological characteristics …, 2015], main hydrological characteristics of the Volga runoff for modern periods were calculated. In this paper, the calculation has evolved; the authors provided quantitative assessment of changes for different types of water regime in the Volga basin.

MATERIALS AND METHODS

Monthly averaged water discharges for selected representative stations were used to calculate the annual flow distribution of rivers: the Lower Volga (37 stations), the Kama (68 stations), the Upper Volga basins (102 stations – Fig. 1) in 1946-1977, 1978-2010, and for the whole period of 1946-2010. The gaps in the time-series of the runoff were filled by using regression equations due to the runoff of the other rivers. However, they were characterized by coefficients of pair correlation of 0.8 or higher.

The choice of the calculation periods is based on the results of earlier analysis of long-term monthly flow fluctuations and our own research [Water Resources of Russia, 2008; Frolova et al., 2013]. Selection of the representative period is also supported by the results of the analysis of long-term (20 years or more) phases of growing and reduced runoff, coupled with the respective phases of cooling and warming [Georgiadi et al, 2014; Georgiadi et al, 2016]. In this paper, we assess the changes carried out on the basis of representative selection periods. Periods of relatively undisturbed natural conditions of the river basins (1945–1977) and periods of high intensity of human impacts and climate change (1978–2010) were identified. All the rivers for annual, winter, summer-autumn, and spring flood have clearly visible phase of runoff increase, the beginning of which can be attributed to the end of the 1970s – early 1980s. All these data refer to the rivers with natural water regime (not disturbed by economic activity) with a range of catchment area from 2,000 to 15,000 km^2.

The study of seasonal river flow required identification of the defined and constant dates of the beginning and the end of seasons for local rivers. The division of hydrological year into seasons depends on the type of annual flow regime. Spring, summer-autumn, and winter were taken as the main seasons for the rivers with spring flood. Depending on the type of the river flow regime and the prevailing type of its use, the hydrological year was divided into the limiting (low flow) and non-limiting (high water) periods, and the limiting period was divided into limiting and non-limiting seasons accordingly. The boundaries of the seasons were defined for the Volga basin in the 1950s [Andreyanov, 1960] under the available limited hydrometric information. At present, there are many stations with long periods of river flow observations. The change of climate conditions observed in the recent decades also required updating and refining relevant characteristics, assumed for calculating the annual river flow distribution. As a result of analysis of hydrographs for more than 200 rivers in 1946-2010, the following periods were selected for further calculations (Table 1).

SPATIOTEMPORAL VARIABILITY OF THE ANNUAL FLOW DISTRIBUTION

Hydrological and meteorological conditions on the Russian plain in 1975–2000 were characterized by high moistening of the territory and an increase in regional river flow. The change of circulation and other

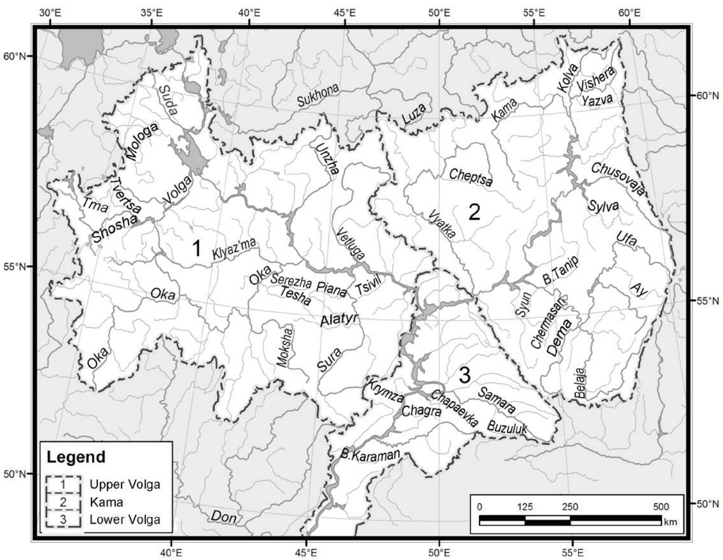

Fig. 1 Studied area

Table. 1. The terms of hydrological seasons for the Volga Basin Rivers

Region	Season		
	Spring	Summer-autumn	Winter
Upper Oka	III-V	VI-XI	XII-II
Lower Volga	III-V	VI-XI	XII-II
Upper Volga (right bank tributaries)	III-V	VI-XI	XII-II
Upper Volga (left bank tributaries)	IV-VI	VII-XI	XII-III
Kama	IV-VI	VII-X	XI-III

related climate-forming processes led to favorable conditions of river flow formation on the East European Plain. Recent climate change in the Volga basin undoubtedly affected the water regime of the rivers and the volume of their annual and low water flow and the volume and height of the spring flood [Water Resources of Russia, 2008; Alexeevsky et al., 2013].

Long-term increase in surface air temperature within the Volga basin occurred mainly due to winter temperature increase. Precipitation changes were significant only in the north-west of the territory. As a result, the long-term changes in snow storage and duration of the snow season were also insignificant. The long-term increase in thaws and, respectively, liquid precipitation, led apparently to the increased snowmelt during the snow season and the inflow of melt water to the rivers. The winter low flow increased, whereas the maximum discharges, typical of the end of the snowmelt period, decreased. Warming also affected the period of intense snowmelt: thawing of the ground accelerated, which brought the surface melt water into the underground component of the water balance; as a result, the maximum (spring) river discharges decreased even further [Kireeva et al., 2015; Dzhamalov et al., 2014].

The statistical processing of annual flow data for the spring, summer-autumn, and winter seasons has been carried out to study the changes of the water regime of the Volga basin rivers.

The spring flood is the main phase and the hallmark of water regime of the Volga basin rivers. The major part of the annual flow of rivers is formed in the spring season. The flow depth in spring in the Volga basin increased from south to north, reaching the highest values in the basins of the Wishera, Yazva, and Colva Rivers. In the basin of the Belaya River, the flow depth value varied considerably, depending on the altitude, from 150-200 mm in the upper reaches to 80-90 mm in the Dema, Chermasan and Syun River basins. In the Samara River basin, this value was 45-60 mm. The spring season flow was 65-70%. Over the last 30 years, the spring flow for the greater part of the Kama basin has decreased by 10%; in the lower reaches of the Belaya River, the decrease ranged from 10 to 20%. In the considered northernmost rivers (the Kolva, Vishera), the increase in the spring river flow was even smaller (5%). In all rivers of the Lower Volga, the decrease in spring river flow and annual flow from 5% in the south to 15-20% in the rest of the basin, was observed. In the Upper Volga basin, the spring flow value increased from 50% in the west (headwater of theVolga, Tvertsa, Shosha, Tma) to 70% or greater in the east (the Tesha and Serezha Rivers and the left-bank tributaries of the Sura River – Piana, Alatyr). In the upper reaches of the Oka River, the spring flood flow was 50-60% of the annual flow, and within the rest of the Upper Volga basin – 60-65%. A decrease in spring flood flow and its share in annual river flow were observed from 5-10% (north) to 20% (south) of all rivers of the territory (Fig. 1). The decrease in the maximum spring flood discharges was typical of the whole period of observations (1946-2010) for the rivers of the Oka basin and the Lower Volga basin. For these rivers, the spring flood started 5-10 days earlier and, consequently, flood duration was longer (Fig. 2).

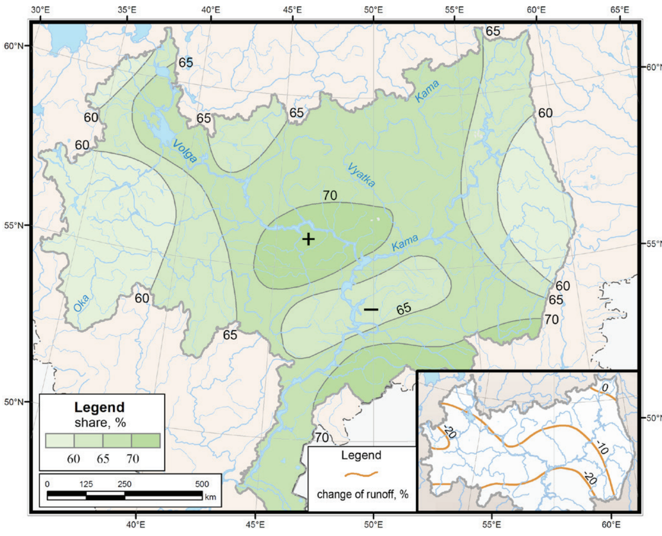

Fig. 2. The value of spring river flow (in % of the annual) in 1978-2010 and its change in 1978-2010 compared with 1946-1977 (%) (the insert map)

For the Oka River and its tributaries, the change of the maximum discharges was 20-40%; for the Lower Volga tributaries, it was 40-70%. This trend was due to an increase in the winter air temperature accompanied by an increase in the number and duration of thaws and, hence, a decrease in pre-spring water reserves and the maximum discharges of the spring flood (Fig. 3).

The spring flood was followed by the summer-autumn low-water period when the rivers are fed by groundwater and drawdown of lakes located in the catchment

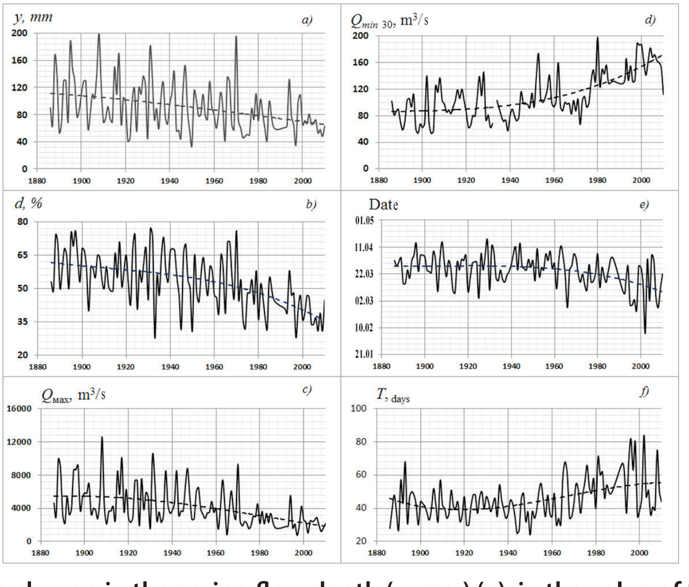

Fig. 3. The change in the spring flow depth (y, mm) (a), in the value of the flood flow (d,%) (b), in the maximum discharges of the spring flood Qmax (m3/s) (c), the minimum 30-day discharges during the open channel period Qmin 30 (m3/s) (d), the date of the spring flood beginning (e), its duration T (days) (f), (the Oka River – Kaluga) (the dotted line shows the trend as a polynomial of the third degree)

area. River flow depth in low-water period also increased regularly from south to north and north-east from 20 to 200 mm. A relatively large river depth is typical of the mountainous part of the basin and the upper reaches of the Kama River. The river flow value in the low water period changed slightly in the territory and was 30-35% for the most territory, and slightly greater than 40% for the basins of the Chusovaya, the Ufa, and other rivers with karst-prone catchments and the rivers of the upper reaches of the Volga and the Oka. The value of low-water flow also varied from west to east, averaging 40-45% in the west, where the flood flow value was high, up to 30-35% in the east. The change of the river flow value in recent decades has been quite significant – from zero in the north-east (the Vishera and Yazva Rivers) to 40-60% or more for the Oka and the Upper Volga basin Rivers.

The lowest river flow was observed in winter, when the rivers are mostly fed by groundwater. The winter flow of all the rivers of the region was less than the summer-autumn one. In small streams, winter flow was often almost absent. The flow depth in winter varied from 15 to 25 mm in the flat part of the Kama basin and in the Upper Belaya and Chusovaya Rivers, and reached its maximum (40-50 mm) in the karst-prone region (the basins of the Ufa, Bystriy Tanip, Sylva and other rivers). For the rivers of the Lower Volga basin, the river flow depth was between 3-5 mm in the south and 10-15 mm in the north. The winter flow depth for the rivers of the Upper Volga basin varied from 10-15 mm in the south-east (the Sura basin) to 35-40 mm in the north-west. The share of winter river flow in the annual value ranged from 5% in the south of the territory up to 10-15% in the north-west and north-east (Fig. 4). It was the greatest for the Upper Oka (up to 16-18%) and decreased in the north-east direction to 5-10% in the Upper Vetluga Rivers. The increase in the winter flow value for the last thirty years has been almost the same as for the low-water period on the whole and reached 40-60% or greater, especially for the south-eastern part of the territory.

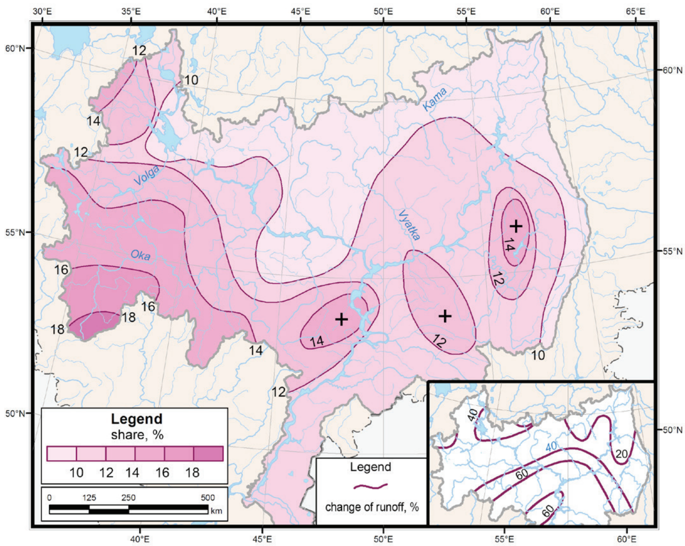

Fig. 4 Value of winter flow (November-March) (in % of annual) in 1978-2010 and its variation in 1978-2010 compared to 1946-1977(%) (the insert map)

It is definitely possible to say that the variability of winter flow in the Volga basin was influenced by two main factors: autumn precipitation (autumn river flow) and air temperature in winter (frosts, thaws). For the parts of the basin with relatively low depth of soil freezing (less than 40 cm) and relatively high groundwater table (less than 2 m), the prevailing factor influencing the increase in the winter flow was the rise of winter air temperatures. Conversely, for the areas with a significant depth of freezing (more than 60 cm) and the groundwater depth of 3 m, precipitation growth and an autumn flow in particular played the main role in the winter flow increase. Basically, the combination of both factors should be taken into account to assess the variability of winter flow.

According to [Lavrov, Kalyuzhny, 2012] for the whole Volga basin, the contribution of each of the considered factors (autumn precipitation, frosts, thaws) to the increase in winter flow was approximately the same. Fig. 5 presents the annual river flow changes of the Oka River near Kaluga.

river flow volume. We applied smoothing and separation rules to the recorded hydrographs from which we compared mean daily flow data with its average annual value. In each case, if mean daily flow data were more than the average annual water flow, the latter was the ordinate of the baseflow line. Otherwise, the mean daily flow data were the ordinate of the baseflow line. We continued this procedure until all data have been analyzed and we provided the derived set of baseflow ordinates. The separated hydrograph indicated the base river flow. The index φ was calculated as the ratio of the volume under the baseflow line (volume of a separated hydrograph) to the volume under the total hydrograph.

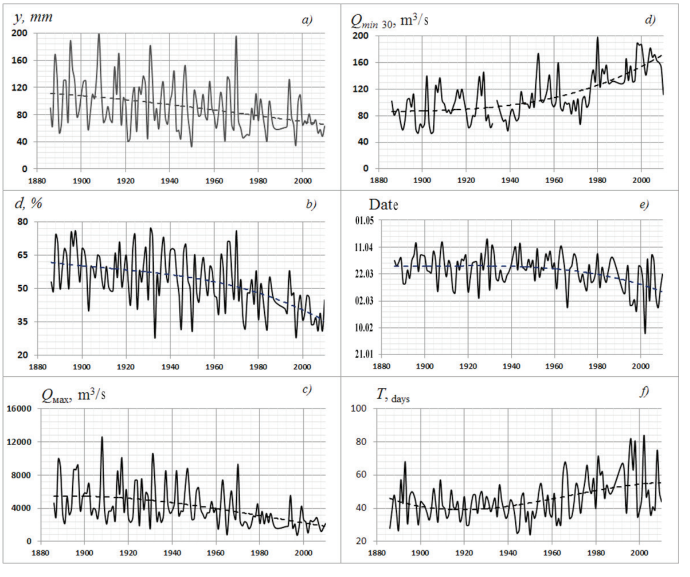

Fig.5 Hydrographs of the Oka River – Kaluga, averaged over different decades

Therefore, seasonal river flow distribution over the territory and its variation for the last decades, in general, followed the geographical zoning; however, the influence of local azonal factors (number of lakes, karst, sandy soils, etc.) often violated this pattern.

THE NATURAL REGULATION OF THE VOLGA BASIN RIVERS.

The irregularity of annual water flow distribution was characterized by natural regulation index φ which corresponds to the share of the "base" flow in annual

The baseflow reflects the natural regulation of the catchment area and its accumulation capacity, so the value of φ index decreases with the decrease in percent lake area, and from the forest to semi-arid zone as well. This index is mainly used for the comparison of different rivers or areas with respect to the value of the most stable ("base",) water resources. For a particular river, the φ value varies from year to year, depending on water regime features, mainly its high-water phase [Andreyanov, 1960]. The spring flood share, in fact, determines its annual irregularity (correlation coefficient R between the spring flood and the annual flow is more than 0.95). The lower the flood flow is the weaker the correlation between the natural regulation φ and the maximum spring discharges. At the same time, φ is affected by groundwater flow which determines the baseflow.

The general feature of natural regulation index in Russia were studied in [Frolova et al., 2010]. For the Upper Volga basin, the φ value, calculated for the period of 1978-2010, increased gradually from 0.55 in the north to 0.8 in the south (the upper reaches of the Oka and the Moksha rivers), and in the west (the upper reaches of the Volga river) (Fig. 6). The average value of φ was approximately 0.65. In 25% of cases, there was a statistically significant trend of index φ increase in 1946-2010. It was most evident in the Moksha and the Sura basins (over 30%), the upper reaches of the Oka and the Volga Rivers (20-30%), and, to a smaller degree, in the Mologa basin, middle and lower reaches of the Vetluga and the Unzha Rivers (10-20%), and almost imperceptible in the northern part of the basin. These changes happened due to the reduction of the snow melt flow value and a significant increase in the underground component. The greatest changes occurred in the southern part of the basin (Fig. 6). All the trends for the entire observation period were statistically significant for the rivers of the Lower Volga Basin, except for one station on the Chapaevka River (Podyom-Mikhajlovka village). The increase in the φ index during the last 30 years was about 30%, compared to the similar previous period. This trend was accompanied by a decrease in the spring flood flow value. For some stations (the Tsivil River – village Tuvsi, the B. Karaman River – village Sovietskoye, the Krymza River – Syzran city and some others), it was over 40%. Analysis of the spring flood and groundwater flow showed that such a change of the φ value took place due to the reduction of the spring flood flow and the increased significance of the groundwater flow [Frolova et al., 2014]. Over the last 30 years, the flood flow value has decreased for the studied rivers by approximately 15%.

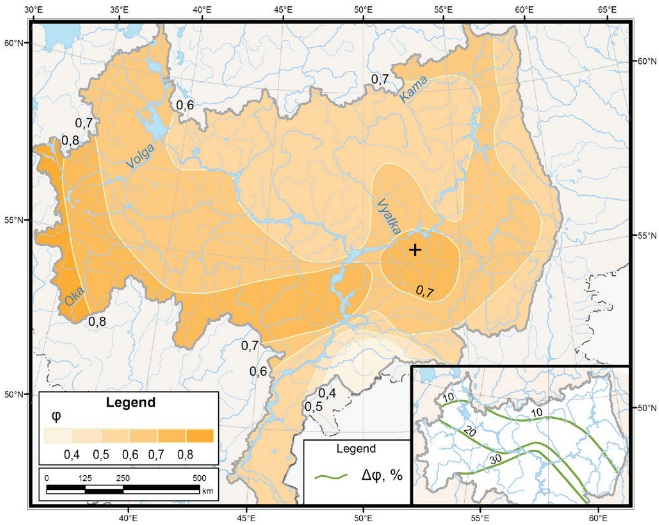

Fig. 6. The average value of the φ index in 1978-2010 and its change in 1978-2010 compared to 1946-1977(%) (the insert map)

The largest values of φ (0.7–0.8) were associated with the uplands with a large erosion depth – the Volga Upland and the Bugulma-Belebey Upland. These areas are characterized by the karst occurrence and increased groundwater feeding. The lowest values of φ (0.3-0.4) were noted for the southernmost of the territory – the Bolshoi Irgiz, the Chagra, and the Chapaevka River Basins. The largest spring flood value (70–80%) was also noted in these areas. In contrast to the Lower and Upper Volga, the statistically significant increasing trends in the Kama Basin were only observed in isolated cases (1946–2010) (the Ay, the Belaya, the Vyatka and the Dema Rivers) due to the slight changes in water regime and the constancy of the flood flow share. For the studied Kama Basin Rivers, the φ value varied within 0.55-0.7, reaching its maximum values in the karst areas (see Fig. 6).

CONCLUSIONS

The annual river flow distribution of the Volga Basin Rivers varied considerably along the territory in accordance with both latitudinal and altitudinal climate change. Besides the climate factors, local characteristics of river basins (the hydrogeological conditions and related karst phenomena, percent lake area, waterlogging, and physical properties of soils) had a great influence on the flow distribution within the year. A statistically significant decrease in the river flow irregularity after 1946 has been revealed for the most of the Volga Basin Rivers. It resulted in the increase in the φ index and change of the seasonal flow, primarily in low-water period, and especially in winter.

Traditionally, the rivers of the European part of Russia had the East European type of water regime, according to B.D. Zaikov's classification [Zaikov, 1944]. This type refers to the first group of rivers with conspicuous spring flood which provides the largest part of the annual river flow. According to "Surface water resources of the USSR" (1972), this value varies between 50 and 100% and 25-50% in the west of the territory. The rivers of the East European type are characterized by a single peak spring flood, starting in March-April and caused by the snow melting, which is, on average, 10 times the maximum discharges of the low-water period. In the autumn, the floods are frequently observed on such rivers. In winter, the low-water period prevails practically across the territory (except for the western and south-western margins with unstable frosty period). A low-water period with varying stability is typical of most of the territory in the summer-autumn period. In recent decades, the water regime of the rivers in European Russia and their annual flow distribution has changed significantly, whereas in the second half of the 1970s, the rivers were characterized as "snow-feeding." By the end of the XXth century, they transitioned to the type of the rivers with "mixed feeding" or even "mixed feeding with prevailing groundwater feeding." This has resulted in the significant increase in the natural flow regulation comparable to the affect of seasonal storage reservoirs.

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CLASSIFICATION OF BENTHIC BIOCENOSES OF THE LOWLAND RIVER TUDOVKA (TVER REGION, RUSSIA) USING COMMUNITY FEATURES

ABSTRACT. Within the joint Russian-Austrian monitoring programme "REFCOND_VOLGA (2006 – 20XX)", monitoring sites were established in the headwaters of the Volga (Tver Region). River Tudovka, a right tributary to the Volga River, was included within this monitoring programme as its catchment is partly protected and has only few anthropogenic activities. The monitoring activities include physico-chemical and hydraulic parameters as well as biota with a focus is on benthic organisms (diatoms and macrozoobenthos). In this work, the longitudinal patterns in community structure are classified in the lowland river Tudovka using a novel feature-based approach taken from signal processing theory. The method first clusters field sampling data into longitudinal classes (upper, middle, lower course). Community features based on the relative frequency of individual species occurring per class are then generated. We apply both generative and discriminative classification methods. The application of generative methods provides data models which predict the probability of a new sample to belong to an existing class. In contrast, discriminative approaches search for differences between classes and allocate new data accordingly. Leveraging both methods allows for the creation of stable classifications. On this basis we show how the community features can be used to predict the longitudinal class. The community features approach also allows for a robust cross-comparison of investigation reaches over time. In cases where suitable long-term data set are available, predictive models using this approach can also be developed.

KEYWORDS: lowland river, monitoring, LTERM, diatoms, macrozoobenthos, nearest neighbour (k-NN) algorithm

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INTRODUCTION

Go-East: Intact Eastern European rivers like the headwaters of Volga River enable the definition of reference conditions (RC) for lowland rivers, according to the EU-Water Framework Directive [Schletterer et al. 2014]. In this context the joint Russian-Austrian monitoring programme "REFCOND_VOLGA (2006 – 20XX)", with monitoring sites in the headwaters of the Volga (Tver Region), was set up [Schletterer et al., 2016]. The reference condition approach became an important tool in aquatic assessments and therefore the identification of reference sites is an important goal [REFCOND, 2003]. However, to understand processes in lentic waters continuous assessments and analyses are needed on a long term perspective, to understand natural variability at reference sites. Thus long term ecological monitoring is of great importance in aquatic environments [Schletterer et al., 2016].

In this paper the longitudinal patterns in community structure are classified in the lowland river Tudovka using a novel feature-based approach taken from signal processing theory. We applied the k-NN algorithm – which comes from machine learning – for the analyses of long term data, in order to structure the dataset and reveal distribution patterns. We also summarize the results obtained within the first 5 years (2006–2010), with a focus on the macroinvertebrate as well as diatom communities, including an overview of the interannual variation in community metrics.

MATERIALS AND METHODS

Study area

The Tudovka River is a right hand tributary of the Volga. Its length is 106 km, with a mean altitude of 250 m and a gradient of 0.87 ‰. The coordinates of the source are 56°26′N 33°04′E and the mouth into the Volga is located at 56°25′N 33°49′E. The catchment exceeds over 1126 km^2 (Fig. 1), with a river network density of 0.69 km / km^2 and it is highly influenced by the surrounding mires (especially in the uppermost reaches). The forest cover (total) amounts to 62%, 12% of the catchment area are bogs and < 1% lakes.

Concerning the hydrological zonation of Tver region, the Tudovka River is included in the Rzhev-Staritskiy hydrological region, which is characterized by highly dissected surface of the catchment, including less water permeable loamy and podzolic soils, lack of lakes in the watershed, as well as representing an average for the Tver region regarding forested and marshy areas [Zagorski, 1967]. The hydrological regime is not influenced, with 68-70% of the annual runoff in spring, 25 % in summer / autumn and 5-6% in winter, i.e. > 50% of the runoff comes from snowmelt. According to the hydrological classification of B.D.Zaykova this is typical for a river of "Eastern European type with high flood in spring, low flows in summer and winter, as well as higher flows in fall". Only short term hydrological studies were carried out in the catchment of Tudovka River, i.e. at the village Priezdovo (near M. Tud) from 1898 till 1899 [Handbook..., 1936] and at the village Molodoi Tud from 1968 till 1970 [Surin, 1976].

The headwater of River Tudovka is located in the transition area of the "Tsentral'no Lesnoy Zapovednik" (Central Forest State Nature Biosphere Reserve), which was established in 1931 to protect "typical forest associations and animals of the central forest region" [Puzachenko et al., 2007]: On the moraine relief of the central part of the Russian plain, "southern taiga" is the predominant ecosystem type. On European scale, the last virgin spruce forests in the southern taiga – since their formation after the last glaciation, unaffected by felling – are found in this area. These forested areas of the reserve are dominated by spruce (Picea abies; 47 %). About 40 % of the forests are formed by birch and aspen; this forest type originated from of serial processes like windfalls or fires. The pine forest, which is characteristic on mires, amounts about 10 %. And along rivers and streams Black-alder forests are situated, that account for about 3 % of the total forest cover.

Also in the middle / lower course of the river, between Redkino and Molodoi Tud, an area of 80 km^2 ("Molodoitudskii Zakasnik"), is protected by the regional government since 1992, meeting IUCN criteria III (Natural Monument) and IV (Habitat/Species Management Area).

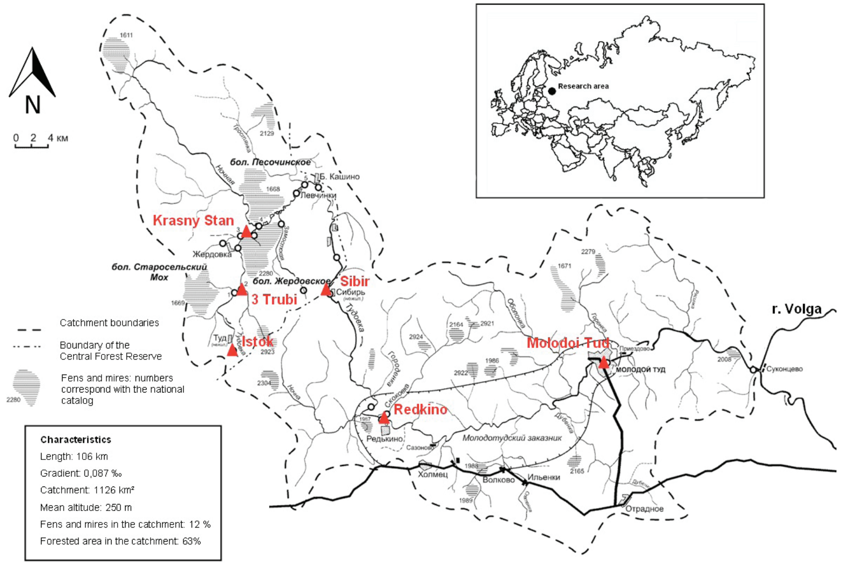

Fig. 1. Basin of river Tudovka: the six sampling sites are indicated

Field work

Within the joint Russian-Austrian monitoring programme "REFCOND_VOLGA (2006 – 20XX)", samples (zoobenthos and benthic diatoms) were taken along the course of the river (Fig. 1) in summer low flow period. Herein we present the date of the first 5 years (2006 – 2010) concerning zoobenthos and 2 years (2006 – 2007) concerning benthic diatoms. In Table 1 a brief characterization of the sampling locations is given.

The zoobenthos samples were taken with a multi-habitat-sampling (MHS) method (HERING et al 2003, modified). A standard frame-net (15x15 cm, 500 µm mesh size) was used and according to the "multihabitat-sampling" method, all available mesohabitats were sampled according to their coverage. As the substrate diversity is quite small in the lowland, we sampled ten squares according to percentages of mesohabitats (e.g. 60 % lithal and 40 % psammal = six samples from lithal and four samples from sand), in total 2250 cm^2. Afterwards the material was rinsed

Table 1. Characterization of the sampling sites at River Tudovka

Site	rkm	km from source	Elevation [m]	Basin [km^2]	Width* [m]	Depth* [m]
Istok	104	2	260 (270)	13,5	1 – 2.5	0.1 – 0.5
3 Trubi	96	10	238	65	2 – 6	0.2 – 1.0
Krasny Stan	87	19	232	192	2 – 3,5 / 7 – 15**	0.5 – 1.5
Sibir	67	39	223	350	15 – 20 (bridge 23)	0.5 – 1.0
Redkino	51	55	207	410	25 – 30	0.5 – 1.5
Molodoi Tud	20	86	187	926	30 – 35	0.5 – 1.5
Mouth into Volga	0	106	170.9	1126	20 – 25	0.5 – 1.5

* during summer low flow period
**upstream/downstream R. Nochnaja

through a 500 µm net and the invertebrates were preserved. All samples were conserved with ethyl-alcohol: in the field the samples were fixed with 96% ethanol and after sorting, the individuals were stored in 70% ethanol. Determination (the identification keys used are cited in [Schletterer, 2009]) and counting was carried out with a binocular, supported with light microscopy.

which can be represented in a parameter space (Fig. 2 (a)). Including new or additional samples is straightforward, as each new point is classified taking into account its nearest k-neighbors using a distance metric in the sample space (Fig. 2 (b)). A variety of different distance metrics can be used to establish the distance between neighbors.

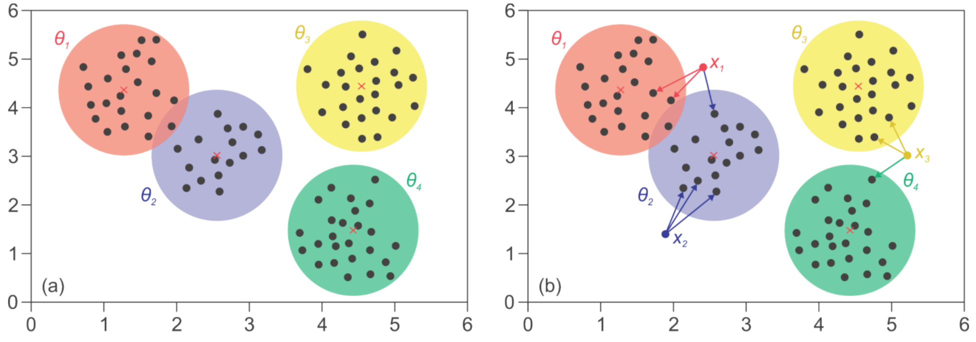

Fig. 2. (a) Distribution of data corresponding to four distinct classes (θ_1, θ_2, θ_3 and θ_4); (b) Classification of new data (x_1, x_2, x_3) using the nearest neighbor approach.

Also benthic diatoms (Bacillariophyceae) were sampled: In most cases at least 15 stones were brushed. In case a location was dominated by fine-sediment (e.g. mud or sand) the uppermost layer of the sediment (2-3 mm) was taken for analyses. The material was stored in ethanol (50 %). The diatom samples were prepared in the laboratory using the H2O2 method (protocol acc. to [Kingston, 1985] cit. in [Schiedele, 1987]). Determination and counting of the diatoms were carried out under the light microscope (1000x, oil immersion), using keys from Krammer & Lange-Bertalot [1986-2004], Prygiel & Coste [2000] and Kelly et al. [2005]. On each mount 300 – 500 valves were counted.

Theoretical background on community features using a species space

The nearest neighbor (NN) algorithm provides a simple nonparametric procedure to perform classification of a collection of sample points (x_1) to different categories (θ_j) [Cover and Hart, 1967]. The method is most commonly applied to perform supervised classification, i.e. when a given category, θ is known *apriori* from a collection of samples

It may be the case that the number and type of classes can be predetermined; however it is often necessary to define the number and division of individual classes using an algorithm such as k-means. This can be accomplished by letting the algorithm determine the definition of the distribution for each category during clustering. Most commonly this is done basing on the minimization of the sum of distances of each class, , to the centroid of its class. The location of the centroid typically becomes more stable with increasing number of samples, thus the k-means classification works best with large data sets.

Here we define an affinity matrix as an interesting particularization and simplification of the NN algorithm which can provide a useful way to study the linkages and interactions between different sampling points. The use of the affinity matrix allows us to uncover relations which may be otherwise difficult to determine using conventional ordination. For instance, if we represent our species distribution, per site as a set of multidimensional complex data points with a possible hidden link between them, we can treat each x as a separate category or class and can thus calculate the distance to any other x. The resulting matrix contains linkages of all the distances between classes. We can then check to see if the selected distance metric is able to correctly evaluate the hidden connections. If so, then the generated matrix will be indicative of the affinity between classes (the lower the distance, the greater the affinity), and in turn it is generally possible to study the relations between the linkages between classes.

Table 2. Example of data structure. The values are indicative of the frequency in percentage on the species in the sample side.

	Istok	3Trubi	Krasny Stan	Sibir	Redkino	Molodoi Tud
Species 1	0.4	0.0	0.0	0.0	0.0	0.0
Species 2	0.0	11.9	0.0	0.7	1.6	0.0
…						
Species n	0.0	0.6	0.0	0.0	0.3	0.0

Data analyses

As discussed in the previous section, the nearest neighbor algorithm provides a simple nonparametric procedure to perform classification of the sample points (xi) to a fixed number of categories (θj). The method is most commonly applied for supervised classification, i.e. training the algorithm using apriori knowledge of the class membership of the training datasets. In this work, we also tested difference distance metrics on the Tudovka data to determine the most robust NN classification workflow.

1) Convert biological data to „species space" for a single site

2) Calculate inter point distance matrix for a single site

3) Calculate KNN between each site

4) Establish classification patterns between sites with additional variables (e.g. morphology)

In this work, each of the studied classes has a set of different dimensions, i.e. $\theta_1 = (a_1, a_2, \ldots, a_n)$ and $\theta_2 = (b_1, b_2, \ldots, b_n)$. For example, in the case under study the sampling sides can be considered as the individual classes, and each dimension will consist of a single scalar quantity, representative of the number of species sampled (Table 2). The percentage occurrence of each species, across the six study sites thus provides the base input data, where the species space neighborhood has as many dimensions as the total number of observed species.

Although it is possible to consider the relative rankings of the species as dimensions, this can mask the relative influence of a given species. Thus the more logical selection for the dimensions will be the frequency of a species.

Once the classes and dimensions are defined, it is then necessary to select a distance metric in order to assess the affinity between the different sites. Considering distance metrics, there are multiple alternatives such as Euclidean distance, Mahalanobis distance, etc. The sum of the distance between two species is used here for simplicity. This distance is known as the Manhattan distance:

$$d(\theta_1, \theta_2) = |a_1 - b_1| + |a_2 - b_2| + \ldots$$

$$\ldots + |a_n - b_n| = \sum_{i=1}^{n} |a_i - b_i|$$

This metric is chosen over the Euclidean distance since considering high dimensionality of the species space vectors, the Manhattan distance usually generates better results, not only because the studied space is not Euclidean [Aggarwal et al., 2001], but also because Euclidean distance is very sensitive to noise [Zimek et al., 2012].

Upon calculating the interclass distance, we then calculate the affinity, defined as:

$$\alpha\left(\theta_1,\theta_2\right)=1-\frac{d(\theta_1,\theta_2)}{\max\left[d\left(\theta_1,\theta_i\right)\right]}$$

This affinity normalizes the results of the distances from 0 to 1, being 0 the most "far" site and 1 the most "closely" related. In contrast to a distance matrix, which is symmetric (see e.g. Table 4, where it can be seen that the species space distance between Istok to 3Trubi is identical to the distance between 3Trubi and Istok), the affinity matrix (see e.g. Table 5) is not symmetric and better reflects the variation of the interspecies distances within each individual site, and similarities to each other (see e.g. Fig. 6).

RESULTS

Physico-chemical characterisation of the Tudovka River

The hydrochemical type of water is "hydrogen carbonate magnesium-calcium" with a mineralization of up to 300 mg/ l in the summer low-flow period. The ionic composition of the water in the river at low water can be characterized by the Kurlov-formula [Kurlov 1928 cit. in Zaporozec, 1972) as follows:

$$\mathrm{M}_{0.208}\frac{HCO_3 94 SO_4 5 Cl 1}{Ca 74 Mg 21 Na 4 K 1}$$

at a distance of 3 km from the source;

$$\mathrm{M}_{0.197}\frac{HCO_3 96 SO_4 3 Cl 1}{Ca 74 Mg 20 Na 5 K 1}$$

at a distance of 19 km from the source;

$$\mathrm{M}_{0.258}\frac{HCO_3 94 SO_4 4 Cl 1 NO_3 1}{Ca 65 Mg 30 Na 4 K 1}$$

at a distance of 55 km from the source;

$$\mathrm{M}_{0.270}\frac{HCO_3 94 SO_4 4 Cl 1 NO_3 1}{Ca 67 Mg 29 Na 3 K 1}$$

at a distance of 86 km from the source.

In its headwaters the Tudovka river is highly influenced by the surrounding mires and in theses reaches organic matter increase: the parameter «color Cr-Co" reaches in some periods of the year up to 600 degrees (in tributaries coming from mires sometimes ≥ 1000 degrees), the permanganate oxidation up to 30 mg/l. Downstream of these river reaches groundwater sources contribute to the river, thus mineralization increases during low flow period up to 300 mg/l. The longitudinal variability of physico-chemical parameters along the course of the river during summer low flow period is presented in Table 3 and Fig. 3. Long-term data regarding physico-chemical parameters is summarized in Fig. 4.

ZOOBENTHOS

At the six sampling sites, from 2006 to 2010, a total of 198 macroinvertebrate taxa were identified, mostly at species level; Ostracoda, Hydrachnidae, Chironomidae and Oligochaeta were treated as one taxon each [Schletterer et al., 2010]. Additionally Chironomidae (46 taxa) and Oligochaeta (13 taxa) were determined for selected years. During the summer low flow period the average density of benthic macroinvertebrates was 1,659 ind. m^{-2} (range 815–2,956) at Istok, 1,959 ind. m^{-2} (range 933–2,880) at 3Trubi, 1,281 ind. m^{-2} (range 760–1,689) at Krasny Stan, 3,990 ind.m^{-2} (range 2,591–5,389) at Sibir, 1,669 ind. m^{-2} (range 1,387–1,844) at Redkino and at M. Tud 2,231 ind. m^{-2} (range, 1,107–3,189). Ephemeroptera (41 taxa), Trichopera (33 taxa), Diptera (21 taxa, exkl. Chironomidae), Coleoptera (19 taxa), Gastropoda (17 taxa) and Bivalvia (7 taxa) as well as Plecoptera and Odonata (each group had 11 taxa) were the most diverse groups. The average number of taxa at Istok was 19 (±4), at 3Trubi 18 (±2), at Krasny Stan 27 (±4), at Sibir 30 (±4), at Redkino 22 (±3) and at M. Tud 34 (±7). The total number of taxa increased along the continuum (Fig. 5 b). Abundances

Table 3. Hydrochemical parameters along the monitoring sites during summer low flow period (August, 2012)

Parameter	unit	№1 – Istok	№2 – 3 Trubi	№3 – Krasny Stan	№4 – Redkino	№5 – Molodoi Tud
distance from the source	km	3	10	19	55	86
date and time of sampling		23.08.2012 12:05	23.08.2012 15:35	22.08.2012 13:00	20.08.2012 18:40	20.08.2012 16:45
temperature	°C	12,4	15,1	12,2	16,5	16,8
pH	ед. pH	7,18	6,95	7,48	8,61	8,31
conductivity	$\mu S\ cm^{-1}$	196	222	233	349	363
colour	°(Cr-Co)	303	117	153	56	36
HCO3-	$mg\ l^{-1}$	98	183	128	195	201
SO42-	$mg\ l^{-1}$	7,7	3,9	3,0	5,9	6,0
Cl-	$mg\ l^{-1}$	0,1	0,1	0,2	0,9	1,0
Ca2+	$mg\ l^{-1}$	28,2	30,9	32,6	45,9	46,7
Mg2+	$mg\ l^{-1}$	8,5	7,3	6,1	10,9	12,2
NH4+	$mg\ l^{-1}$	0,43	0,31	0,33	0,22	0,57
NO2-	$mg\ l^{-1}$	0,02	0,02	0,02	0,03	0,02
NO3-	$mg\ l^{-1}$	0,4	0,4	0,3	2,8	2,7
PO43-	$mg\ l^{-1}$	0,022	0,006	0,029	0,020	0,025
P(total P)	$mg\ l^{-1}$	0,139	0,114	0,131	0,107	0,141
Fe (total Fe)	$mg\ l^{-1}$	0,39	0,45	0,22	0,10	0,08
Si	$mg\ l^{-1}$	3,9	2,5	2,4	2,1	2,8
COD (KMnO4)	$mg\ O\ l^{-1}$	26,0	14,6	16,8	5,8	4,6
BOD5	$mg\ O\ l^{-1}$	6,1	0,5	0,7	0,4	0,6
Mn2+	$mg\ l^{-1}$	0,02	0,03	0,03	0,02	0,03
alkalinity	$mEq\ l^{-1}$	1,6	3,0	2,1	3,2	3,3
hardness	$mEq\ l^{-1}$	2,1	2,1	2,1	3,2	3,3
solid residual (mineralisation)	$mg\ l^{-1}$	128	134	124	150	174

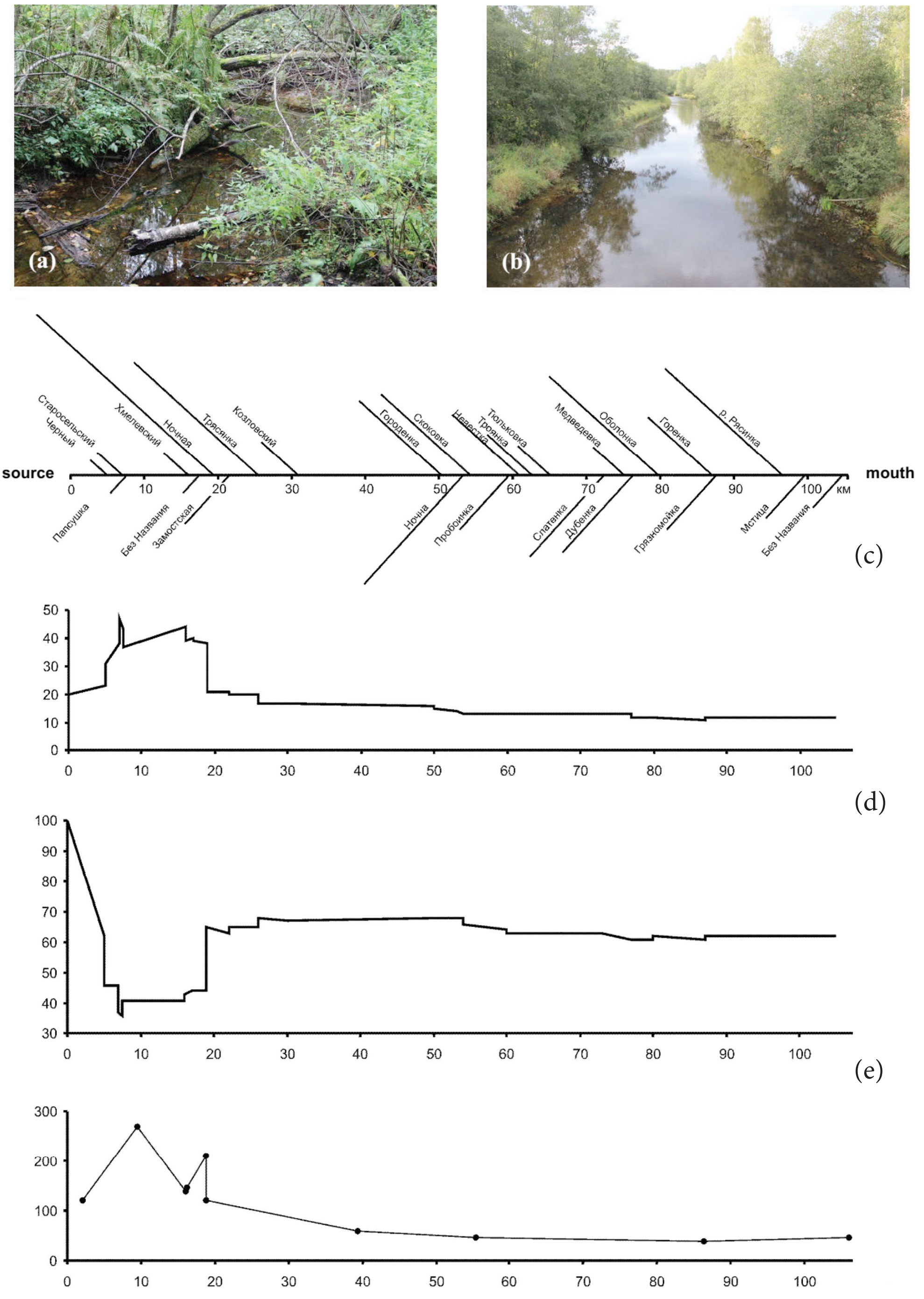

Fig. 3. The Tudovka River near its source "Istok" (a) and the lower course at Redkino (b); hydrographical schema of the Tudovka river with its main tributaries (c); the next graphs illustrate the changing parameters along the longitudinal course of the river: (d) amount of mires in the catchment (%), (e) forest in the catchment (%) and (f) the color (°) of the water (1.05.2005) (after: [Zhenikov et al 2007], modified)

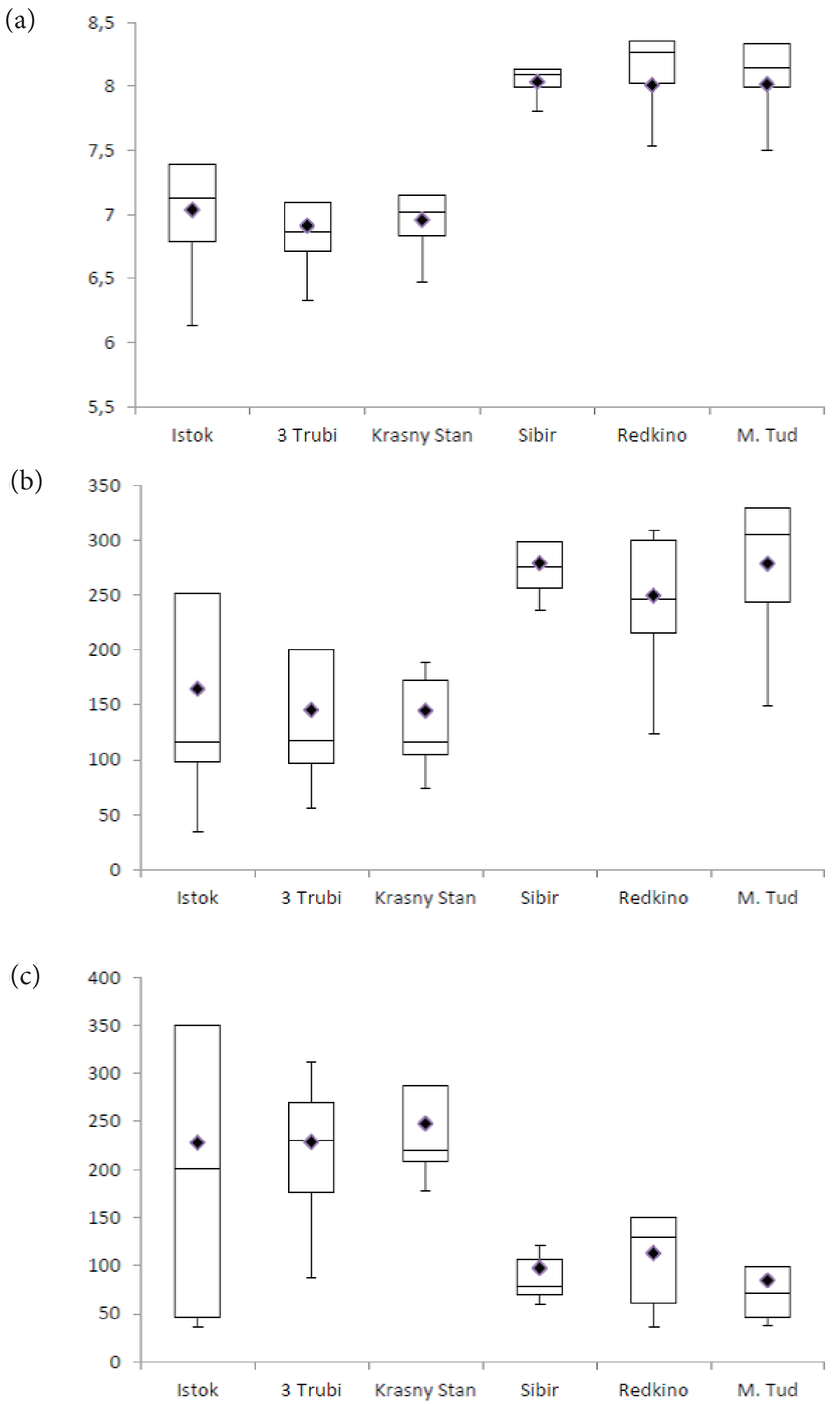

Fig. 4: Physico-chemical characterisation of the investigated sites, based on field measurements in the years 2004 – 2010: (a) pH, (b) conductivity, (c) colour. For the different stations, the amount of measurements are not the same, i.e. Istok (n = 10), 3 Trubi (n = 10), Krasny Stan (n = 9), Sibir (n = 4), Redkino (n = 9), M. Tud (n = 10).

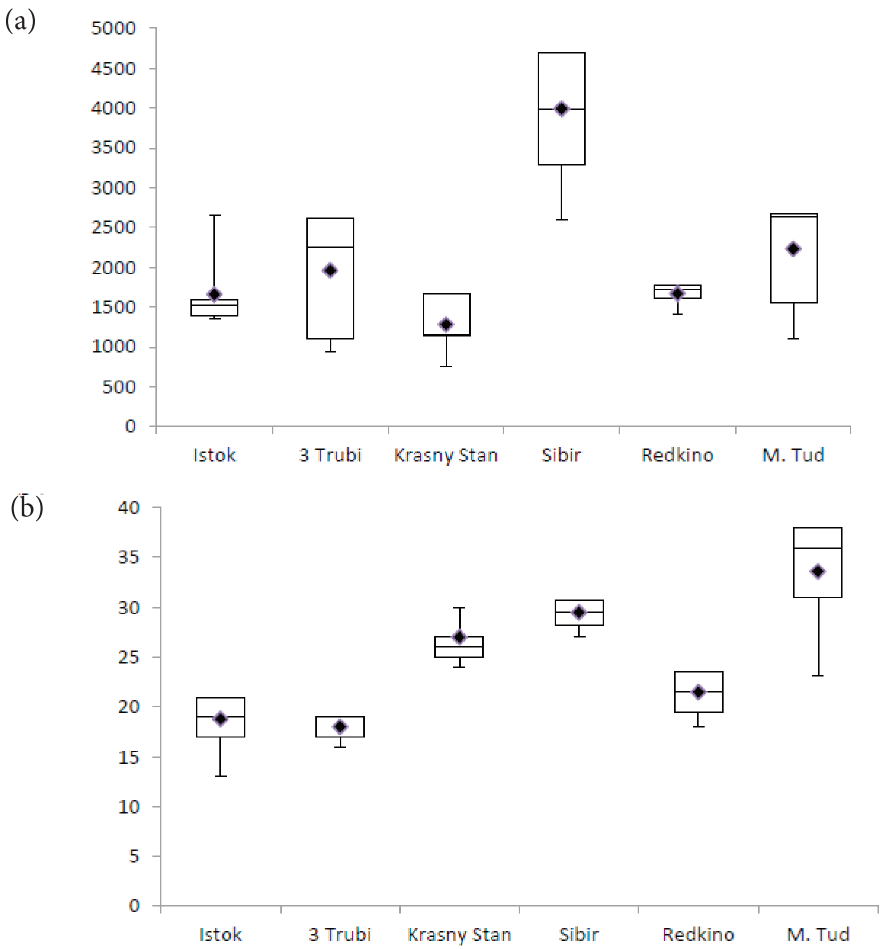

Fig. 5: Characteristics of the zoobenthos community during summer low flow period, based on samples from 2006 – 2010: (a) individual per m² and (b) number of taxa (chironomidae + oligochaeta handled as 1 taxon each). The amount of samples is usually 5, while less samples are available for Sibir (n = 2) and Redkino (n = 4).

Table 4. Distance matrix between all sites based on cumulative species data from 5 years [Schletterer et al., 2010]. Shortest distances corresponding to the nearest neighbours in species space are indicated (red / bold).

	Istok	3Trubi	Krasny Stan	Sibir	Redkino	Molodoi Tud
Istok	0.00	**114.33**	129.15	149.94	126.39	131.87
3Trubi	114.33	0.00	**110.00**	168.11	119.66	138.04
Krasny Stan	129.15	**110.00**	0.00	165.47	121.20	142.74
Sibir	149.94	168.11	165.47	0.00	165.93	**137.27**
Redkino	126.39	119.66	121.20	165.93	0.00	**109.24**
Molodoi Tud	131.87	138.04	142.74	137.27	**109.24**	0.00

Table 5. Affinity matrix used to evaluate the similarity of investigation sites to each other. The affinity matrix is not symmetric because affinity is normalized by the maximum distance observed across all other sites (Eqn. 2). Similar reaches are marked in red, the maximum affinity is always 1.0.

	Istok	3Trubi	Krasny Stan	Sibir	Redkino	Molodoi Tud
Istok	1.00	0.24	0.14	0.00	0.16	0.12
3Trubi	0.32	1.00	0.35	0.00	0.29	0.18
Krasny Stan	0.22	0.34	1.00	0.00	0.27	0.14
Sibir	0.11	0.00	0.02	1.00	0.01	0.18
Redkino	0.24	0.28	0.27	0.00	1.00	0.34
Molodoi Tud	0.08	0.03	0.00	0.04	0.23	1.00

Fig. 6: Affinity diagram showing which sites are the most strongly related. In total, two distinct groups were formed, containing the sites 1 2 3 and 4 5 6. Double arrows indicate bilateral affinity, e.g. 3Trubi and Krasny Stan were found to be most strongly related to each other, whereas Istok was found to have the strongest affinity to 3Trubi.

were quite similar in the upper course (mean values = 1,659; 1,959 and 1,281 ind. m^{-2}, respectively), while they were higher in the middle and lower course (Fig. 5 a).

In total, six sites were compared using cumulative zoobenthos data from the years 2006-2010 [Schletterer et al., 2010], and the distance matrices and affinity matrices were generated using the KNN species space classification method. As shown in Table 4, the distance matrix for all six sites reveals that Istok, 3Trubi and Krasny Stan can be considered as a group of nearest neighbors, and Sibir, Redkino and Molodoi Tud constitute a second group. After normalization, the affinity matrix results can be used not only to determine which sites are the closest matches in terms of the species space affinity (Table 5), but also how interrelated they are to one another (Fig. 6). Here it was found that the affinities between the six sites followed the same general pattern of two distinct groups, where it was found that for the first group, 3Trubi and Krasny Stan were more similar to each other, and in the second group Redkino and Molodoi Tud were reflexively similar as well. Different species assemblages are linked to certain biocoenotic regions along the continuum (crenal rhithral potamal) and certain longitudinal distribution patterns for instance are linked to different species [Moog, 2002]. A k-NN classification of the benthic community – based on presence / absence (p/a) of species clearly revealed longitudinal patterns, i.e. a classification between the source (Istok), the upper course

Table 6. Distance matrix between the sampling locations based on diatom samples collected in 2006 for five of the investigation reaches. The species space nearest neighbors are indicated (red / bold).

	Istok	3Trubi	Krasny Stan	Sibir	Molodoi Tud
Istok	0.00	185.10	178.10	171.70	**162.50**
3Trubi	185.10	0.00	**144.80**	191.80	183.00
Krasny Stan	178.10	**144.80**	0.00	194.20	180.20
Sibir	171.70	191.80	194.20	0.00	**114.20**
Molodoi Tud	162.50	183.00	180.20	**114.2**	0.00

Table 7. Affinity matrix of diatom similarity of five investigation sites.

	Istok	3Trubi	Krasny Stan	Sibir	Molodoi Tud
Istok	1.00	0.00	0.04	0.07	0.12
3Trubi	0.03	1.00	0.25	0.00	0.05
Krasny Stan	0.08	0.25	1.00	0.00	0.07
Sibir	0.12	0.01	0.00	1.00	0.41
Molodoi Tud	0.11	0.00	0.02	0.38	1.00

Fig. 7: Affinity diagram of the 2006 benthic diatoms. Two groups were also found, the major difference being that Istok was more closely linked with Molodoi and Sibir instead of 3Trubi and Krasny Stan.

(3Trubi and Krasny Stan), the middle course (Sibir) and the lower course (Redkino and Molodoi Tud).

BENTHIC DIATOMS

2006 Diatoms.

To compare the methodology using an additional species, diatom data sets from 2006 and 2007 were also collected, for five of the six sites, excluding Redkino. The distance (Table 6) and affinity matrices (Table 7) were calculated in the same manner as for the composite zoobenthos dataset. It was again observed that the KNN species space classification broke the five sites into two distinct groups, the first consisting of 3Trubi and Krasny Stan, the second group was made up of Istok, Sibir and Molodoi Tud. Considering the 2006 diatom dataset, it was found that once again 3Trubi and Krasny Stan were self-similar, however this must be the case with only two members in a group (Fig. 7). Considering the second group, the investigation reaches Sibir and Molodoi Tud were found to be the most similar.

2007 Diatoms.

The final data set compared was using 2007 diatom data. All six investigation reaches were available and were compared using the same methodology for the species space distances (Table 8) as well as the affinity matrix (Table 9). An interesting observation is that the same two groups emerged (Fig. 8) from the 2007 diatom data as for the zoobenthos and 2006 diatom data sets, indicating that the proposed KNN species space method may be able to provide robust classification across multiple sites and years. The affinities were also identical to the zoobenthos analysis, the only difference being that in the second group, it was found that Sibir and Molodoi Tud were the most self-similar, as was also found in the 2006

Table 8. Distance matrix between the sampling locations based on data collected in 2007 for five of the investigation reaches. The species space nearest neighbors are indicated (red / bold).

	Istok	3Trubi	Krasny Stan	Sibir	Redkino	Molodoi Tud
Istok	0.00	174.80	**143.60**	180.00	179.60	185.10
3Trubi	174.80	0.00	**134.60**	189.20	171.60	190.10
Krasny Stan	143.60	**134.60**	0.00	181.80	164.80	179.70
Sibir	180.00	189.20	181.80	0.00	109.40	55.10
Redkino	179.60	171.60	164.80	109.40	0.00	102.70
Molodoi Tud	185.10	190.10	179.70	**55.10**	102.70	0.00

Table 9. Affinity matrix of diatom similarity of the sampling locations.

	Istok	3Trubi	Krasny Stan	Sibir	Redkino	Molodoi Tud
Istok	1.00	0.06	0.22	0.03	0.03	0.00
3Trubi	0.08	1.00	0.29	0.00	0.10	0.00
Krasny Stan	0.21	0.26	1.00	0.00	0.09	0.01
Sibir	0.05	0.00	0.04	1.00	0.42	0.71
Redkino	0.00	0.04	0.08	0.39	1.00	0.43
Molodoi Tud	0.03	0.00	0.05	0.71	0.46	1.00

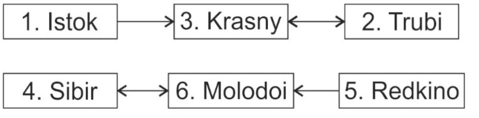

Fig. 8: Affinity diagram of the 2007 benthic diatoms. Two groups were also found, with the same reaches (1,2 3 and 4,5,6) as in the 2006-2010 zoobenthos classification.

diatom analysis. This also indicates that the differences between the community structures may be detected by the method, but that the overall grouping of the individual sites remains robust. Due to the small number of investigation reaches, a larger study would be required to substantiate this.

DISCUSSION AND OUTLOOK

Our analyses underline that the KNN algorithm is suitable for the classification of benthic biocenosis. Application is possible on species level as well as using traits (e.g. functional feeding types). The methodology is straightforward and relies only on the accuracy of the bioassay for each site. The proposed species space concept enables a detailed comparison of study sites and their interrelation, thus it is a useful tool for the comparison of large datasets, i.e. Long Term Ecological Research and Monitoring (LTERM) data. Using different biological components as well as the combination of all of them could even provide more robust classification and further interclass differentiation of investigation reaches.

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ECOLOGICAL AND MICRO-TOPOGRAPHICAL IMPACT OF *MESSOR EBENINUS* AND *MESSOR ARENARIUS* ANTS ON ARID LOESS RANGELANDS OF THE NORTHERN NEGEV

ABSTRACT. Improper land management, such as over-grazing in arid areas, has negative effects on the local ecosystems for both the short and the long term time periods. An effective rehabilitation scheme requires human interference by introducing ecosystem engineering organisms together with activities that encourage the spreading and the reproduction of the local plant and animal species. Most of the former studies in arid lands focused on shrubs as engineering species, and much less on other organisms. The major focus of this study was on assessing the impact of *Messor ebeninus* and *M. arenarius* on the micro-topographic patterns of arid areas using unique spatial statistical tools designed solely for this purpose. As a case study, the nests' sizes and their distribution were compared between two adjacent shrublands with similar geographic outlines during 2008 and 2015.One of the shrublands was moderately grazed for the last 20 years (at the far past it was exposed to over-grazing), while the other one is still exposed to over-grazing. The results collected in 2014 at the shrublands and at the adjacent loess area demonstrate the spatial ecosystem ability of the *Messor sp.* to engineer and beneficially modify their environment by enlarging the water conserving area, increasing the soil fertility and vegetative productivity, and finally accelerating the whole area rehabilitation.

KEY WORDS: *Messor ebeninus* and *Messor arenarius*, Micro-topographic impacts, Ecosystem engineers, Rangeland management temporal changes, Shrub' patches vs. ants' nests

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INTRODUCTION

Overgrazing has negative effect on the ecological system of the Northern Negev [Olsvig-Whittaker et al. 2006], and other arid areas all over the globe [Belsy 1992]. This negative impact has been demonstrated by decrease in flora and fauna biodiversity [Leu et al. 2014], damage of soil properties [Greenwood and McKenzie 2001], change in the micro-topographic structures (shape, size and distribution of different landscape patches) [Steinberger et al.1992; Pablo and Martin 2006], and in some cases, even damage to the macro-topographic structures (sheet erosion, rills and gullies formation) [Hoffmann et al. 2014]. In extreme cases, such as at wide parts of the Northern Negev, the area rehabilitation cannot rely solely on natural processes. Therefore human interference including drastic change of the land management is required [Aronson et al. 1993].

The so far used management for rehabilitation of over-grazed*[1] areas is based on the complete enclosure of a given area and prevention of any grazing at it for several years [Asefaet al.2003]. Although such management policy has its ecological advantages, it also has crucial drawbacks associated with its long term application such as high costs, and the dependency of the local population on grazing as the main income resource [Sidahmed 1996].

An alternative approach that allows accelerating the natural rehabilitation processes is based on introduction of biological ecosystem engineers [Byers et al. 2006]. Ecosystem engineers were defined by Jones [1994] as: «Organisms which create modify or destruct habitant and directly or indirectly influence on the availability of resources for other species by generating physical changes in biotic and abiotic parameters». The 'ecosystem engineer' based approach was studied mainly on plants with an emphasis on shrubs [Sarah 2002] and less on other taxonomic groups such asisopods [Shachak and Jones 1995], porcupines [Wilby and Shachak 2004] and ruminants herds [Greenwood and McKenzie 2001;Stavi et al. 2009]. While many studies stressed the effect of ants on the areal flora seedbank [Wilby et al. 2001], nest fertility [Cammeraat et al. 2002], and even local insect population [Offenberg 2015], none of them took into account their spatial patterns such as spreading, correlation to the other areal bio-patches (for example, shrub), and the effects of changes inarea management on these patterns.

Former observations of our group at the continuously over grazed areas all over the Negev revealed death of shrubs, and lack of new shrub establishment due to consecutive dry years. While in genera no significant change was observed in ant nests number and size, some of them did demonstrate an increase in size. Additionally, the nests' herbaceous cover, both of the abandoned and the active ones, was higher and more productive than that of the surrounding area.

The term 'harvester ants' group is related to species which consume seeds as their main feeding resource. The ants collect the seeds and store them in nests, which they built at the communal chambers. In arid areas they have an important role as seeds dispersal agents for 'myrmecochorous' plant species, while in case of other plant species they serve as seeds predators [Arnan et al. 2012]. One of the interesting phenomena related to harvester ants is their colony spreading into new locations and establishment of 'daughter' nests. Locating to the new colony (daughter nest) is done by two parallel mechanisms. The first mechanism is patrolling in which the nest's queen appoints patrollers to evaluate viability of the soil in a given plot for the daughter nest by digging 'experimental holes'. The collection of these holes is defined as a 'patrolling route' [Gordon 1987]. The second mechanism is a 'Nuptial flight' in which young virgin queens from the source nest are carried by the wind and those that find adequate places, build new colonies and nests [Hoelldobler, 1976].

[1] This term will be used in the text for areas that were exposed to unrestricted grazing and that have observable decrease in annuals cover, and/or their degradation along the years.

While in general these mechanisms are clear, many behavioral questions' mainly regarding the data transmission of the patrollers' findings to the young queens and its role in their final decision for colony location' remain unanswered. Many studies were carried out regarding behavioral, chemical, and physical patterns of the harvester ants [Cammeraat et al. 2002]. Additive studies were implemented regarding their local effect on plant species [Brown and Human 1997]. Nevertheless, there are still wide gaps regarding their spatial impact on fertility and productivity of agricultural fields.

Specifically, the objective of this study was to define the spatial impacts of harvester ants on grazing lands under different 'field conditions' (drought, different rangeland management, etc.).We chose as a research site area in the northern Negev as it has dominant rangeland use [Ginguld et al. 1997]with large presence of the *Messor ebeninus* and *M. arenarius* harvester ants (the most wide spread ant species among the 23 species that are known in Israel) [Steinberger et al. 1992; Ofer 2000]. Due to the fact that the wide part of the northern Negev is defined as 'shrubland' (Shachak et al. 1998), comparisons of the nests distribution were implemented on shrub patches and the respective inter-patch area (matrix).

TOOLS AND METHODS

Site of study

The research took place in Chiran area (East-West: 34°59'04"E, North-South: 31°19'34"N), North of Hura Bedouin settlement, and South of Yatir forest, Northern Negev, Israel. The area has hilly topography (250 m ASL). The soil is Sand-Clay [USDA 1999].

Climatically, the area is located in the transition zone between the arid and semi-arid regions with annual mean precipitation of 150 and 250 mm originating from winter rains (November-April) and convective storms [Goldreich 2003]. The rains are characterized by high inconsistency with regard to their amounts, locations and intensities [Ward et al. 2000].

The temperatures at the cold season (December-February) are 8.1 -19.2^{0}C, while those of the hot one (June-August) are 21-34^{0}C (Data from Israel Meteorological Services).

This research is an episode of the much larger long term study on arid shrublands at the area, started at 2006 and that continues till this day. The coreof the study was implemented between 2008 and 2010. Although the rain amounts were similar between2008 and 2009, 155 and 159 mm year^{-1} respectively, due to the lack of homogeneous rain spreading, 2009 was considered as the drought year, as opposed to 2008. In 2010 the precipitation amounts were 237 mm per year (IMS).

Ecologically most of the area is defined as steppe and rocky shrubland [Goldets and Boeken 2004; Stavi et al. 2009] which has been exposed for decades to unrestricted and intensive grazing accompanied by a decrease in floral cover and enhanced land degradation [Olsvig-Whittaker et al. 2006]. The intensive grazing has led to low perennials cover (60-700 shrubs per hectare)' and massive soil erosion phenomena [Lin et al. 2010].

Between the years 1992 and 1994 several family farms were established by authorized farmers with the objective of decreasing the soil erosion, and land rehabilitation by implementing sustainable grazing management illumination of grazing at annuals germination stage, reduced in annuals growth and spread grazing at the dry season [Swanson 2008].As a result a gradual rehabilitation was observed with regard to the soil fertility, whereas the surrounding overgrazed area continued to experience a dramatic decrease of the vegetation cover together with soil erosion acceleration along the years.

Two plots located inside the representative shrublands were chosen, each having 15X15m area, 25% rockiness, south aspect and similar vegetation composition based mainly of shrubs from Irano-Turanian and Saharo-Aribian biogeographical origins, and *Sarcopoterium spinosum* from Mediterraneanone [Yair and Danin 1980]. The moderately grazed plots was located inside Yatir family farm, while the over-grazed one was located 200m east, outside of all family farms. It has to be stressed that the definition of area as 'over-grazed' was based on several observations, measurements and data from the local farmers with regard to the state of vegetation cover and soil erosion prior to the study. The soil state findings were compared to the data and the definitions of Olsvig-Whittaker et al. [2006]. Complementary observations were collected in 2014 from additional site. This site, which will be defined along the text as 'wadi Atir, is located in the south part of Eshtamoa basin (part of which has been defined by the local population as wadi Atir), 7 km southeast from the main site of 0.4 ha size. In the past, the site and its surroundings suffered from massive soil erosion, but from 2012 it is under rehabilitation processes due to constructions of topographic soil structures along its streambeds- called 'limans' [Prinz and Malik 2002]. Parts of the remaining areas were tilled and sowed with winter cereals and rain-fed, while other sections were fenced and were left un-managed in order to serve as control plots for agricultural research. The closeness of the differently managed plots allowed continuous assessment of ants' settlement in them [Mor-Mussery and Leu 2012].

Patches analysis

In order to accumulate Folgarait [1998] finding on the effect of ants on ecosystem functioning, we tested unique methodology which based on field work and lab analyses.

Patch definition and documentation at field.
Arid shrublands are defined as composed of scattered shrubs and other perennials that are located on micro-topographic patches surrounded by matrix [Goldets and Boeken 2004]. In our primary observation all over the Negev, we noticed the similarity of the micro-topographic patterns of the landscape patches which included presence of ant nests and perennials and their visual difference from the surroundings.For this study we examined the effects of the nests and perennials using the same methodologies as did Steinberger et al. [1992].In order to analyze the different landscape patches in comparison to the surroundings, at both sites we defined the patches' patterns as follows:

a. Loose area with unique micro-topographic predominant patterns as compared to the surrounding area (raised or lowered).
b. Area without soil disturbances caused by human or fauna activities (for example, rodents diggings), except ants activity.
c. Area which includes nests, perennials (shrubs, geophytes, hemicryptophites and perennial herbs) and several annuals which were documented in literature as having noticeable impact on their ecosystem[Lacey et al. 1989].

Note. In stand-alone case, the 'nests' size, was defined based on the total area of its mounds (composed from reflected ants entrance holes) and reflected dumps [Rissing, 1986]. Nests with additional bio-groups were treated based on their total patch area. Due to research limitations the *Messor ebeninus* and *M. arenarius* nests were documented altogether, although their ants different foraging characters [Avgar et al. 2008].

Division of the patches' biogenic components into study groups. In order to define the interactions between the nests and the biogenic activity inside the patches, the studied organisms inside the patches were divided conceptually into three groups: 'shrubs' (including *Thymelea hirsuta, Pituranthos triradiatus, Noaea mucronata,* and *Sarcopoterium spinosum),* 'perennial herbs' *(Asphodelus ramosus, Echinops adenocaulos* and *Centaurea hyalolepis)* and 'ants'. The nests activity (or abundance) was defined based on ants' entrance observations at the time of study based on Gordon and Kulig[1996] principles. Patches which contain the same 'examined group', were defined along the text as 'sub-plot'. The matrix, which represents the area between the patches, was also defined as sub-plot.

Size and distribution analyses of the patches. The longitudinal and lateral axes of the different patches and ants' nests were measured, and their areas were calculated based on elliptic shape form [Mailleux et al.2003]. Specifically, the sizes of the nests were determined based on the ants' external activities (location of entrance holes, soil dumps, litter dumps etc.). Based on Gustafson [1998] findings, we implemented unique analysis methodology for the composite patches (those that include more than one of the examined groups). Each composite patch was analyzed as several separate ones. Each of them contained one examined group having the size of the whole source patch. For example, source patch (area with axes of 0.5 and 0.6 m) which included ant nest and *Noaea mucronata*, was treated as two elliptic patches with size of 0.24m^2, one with 'shrubs' and the other with 'nests'. The mean of the allocated patches sizes per each sub-plot was used to assess the impact of the 'examined groups' on the area micro-topography' and as result on the whole ecosystem parameters by assuming that higher value represents bigger influence [Mor- Mussery et al. 2013]. Importantly, for the calculations, the number of individuals from examined groups was not taken into account, only their appearance was valid. Using this type of analysis, we defined additional factor per each 'examined group' termed 'allocated heterogeneity' that expresses the number of different groups in the studied patch. For example, in patch with ants' nests and *Echinops adenocaulos* perennial herb, the 'nests' and 'perennial herbs' groups got the value '2' for 'allocated heterogeneity' parameter, while in patch with *Thymelea hirsuta* shrub value of '1' was allocated per the 'shrubs' group. Afterwards, per each 'examined group', the ratio between composite appearances ('allocated heterogeneity' equal or above '2') and the total ones was calculated.

Defining the correlations between the nests development and shrubs growth

One indication for the reciprocal impacts between the ants and plant development is analysis of their sizes in combined patches [Gustafson, 1998].

For this propose we chose the Thymelea hirsuta which is one of the most widespread shrub species at the site of study. We noticed that in most Thymelea h. patches there were ants' nests. For examining the correlation between the *Thymelea h. growth* and the nest development, we compared the *Thymelea h.'* canopy and nest sizes (only in patches containing stand-alone *Thymelea h.)*. Additional comparisons were done in patches containing groups of *Thymelea h.* by comparing their number and the nest sizes [Rico-Gray and Oliveira 2007].

Herbaceous productivity analysis. The most representative parameter for identifying degradation or rehabilitation process in arid areas is the herbaceous productivity [Lin et al. 2010]. For measuring the herbaceous productivity, the herbaceous samples were harvested randomly at March 2010 using 20X30cm iron frames from sub-plots containing stand-alone 'examined group'(five replicates per each sub-plot). The samples were dried in 60^{o}C per 48h according to the protocols of Sava [1994]. The values were expressed as Kg per m^2. It has to be stressed that the samples from the nests were taken from their edges in order to minimize the damage [Wagner and Jones 2006]. In addition to the comparisons of the average herbaceous productivity between the different sub-plots, the obtained values were used for estimating the contribution of the nests and shrub 'examined groups' to the herbaceous productivity of the whole shrubland by subtracting the obtained matrix herbaceous biomass from the examined group ones and multiplying the results by their coverage ratio. Here we bring calculation example for the 'shrubs' defined group. The calculation was carried out in the same manner for the nests. The equations which were developed based on Wagner et al. (2004) findings, were as follows:

$$ShrubsAr_{HerbBM.Contribution}=(Shrubs_{HerbBM}- Matrix_{HerbBM}) *Shrubs_{Coverage} * 10$$

$ShrubsAr_{HerbBM.Contribution}$ -The herbaceous biomass contribution of the 'shrubs' (compared to the hypothetic state of an area composed of matrix without patches) [Ton ha^{-1}]
$Shrubs_{HerbBM}$ - The average herbaceous biomass of the 'shrubs' per area unit [Kg m^{-2}]
$Matrix_{HerbBM}$ - The average herbaceous biomass of the matrix per area unit [Kg m^{-2}]
$Shrubs_{Coverage}$ - The partial coverage of the shrubs' patches from the entire area.
'10' is for units matching

Soil properties analyses. In order to assess the effects of Messor ebeninus and M. arenarius on soil nest [Dosta´let al. 2005] describe on Lasius flavus ants, at April 2009 soil samples of 0.5Kg were collected from the moderately grazed plot. All samples were taken from the 20 cm thick upper soil layer which represents the root zone of the most annuals [Schenk and Jackson 2002]. The samples were transferred to Gilat Field Services Lab for nutrient analyses, based on their importance to ecosystem fertility including Soil Organic Carbon, N_{total} and P-PO_3 [Zaady et al., 2001]. Additionally to these analyses, two parameters reflecting the water absorption and holding capacities were analyzed in the different sub-plots, including field capacity and infiltration schemes [Rico-Gray and Oliveira 2007]. All factors were measured with four replicate sper each sub-plot, based on Sava [1994] protocols. The obtained values were also used for estimating the contribution of the nests and shrub patches to the whole mineral content of the shrubland. This was achieved by subtracting the matrix values from those of the sub-plots and multiplying the results by their coverage rate as follows from the Potassium content measurement example:

$$Nest_{P.Contribution}=((Nests_{(P)}-Matrix_{(P)})*Nests_{Coverage})*0.2*1.2*10$$

$Nest_{P.Contribution}$ - The nests contribution to the Potassium amount of the root zone of the shrubland [Kg ha^{-1}]
$Nest_{(P)}$ - The average Potassium concentration per nest volume unit [Kg m^{-3}]
$Matrix_{(P)}$ -The average Potassium concentration per matrix volume unit [Kg m^{-3}]
$Nests_{Coverage}$ -The relative cover of the nests from the whole area (expressed as decimal fraction).
'0.2' represents the root zone of the annuals [m]
'1.2' represents the Bulk density [Kg per m^{-3}]
'10' is for units matching

Note. The specific weigh per volume was calculated by averaging the drought weight of five samples with known volume (the samples were of half litter volume and dried overnight at 105°C)[Sava 1994].

In order to obtain a more comprehensive view on the impact of the nests on the water balance of arid ecosystem, a set of infiltration measurements were taken from wadi Atir site in bare, *Messor abensis* nests, and *Anabasis setifera* patches (the most common shrub species at the site of study). The measurements were implemented using Decagon® mini-disk infiltrometer for duration of six minutes [Decagon, 2012].

Statistics analyses. Confidence analyses between the different plots with regard to the herbaceous biomass, patch sizes, nutrients concentrations, etc. were implemented using ANOVA test. The correlations between the nests sizes and *Thymelea h.* growth were analyzed by linear regression. For both types of analyses we used JMP® ver. 5.0 (α=0.05).

RESULTS

The quantitative analysis of 2008 and 2009 findings strengthened the trends observed from the preliminary observations. The nests were much widely distributed in moderately grazed shrubland than at the other patches. Our findings regarding the coverage of the nests in the moderately grazed area at 2009 were similar to the preliminary observations

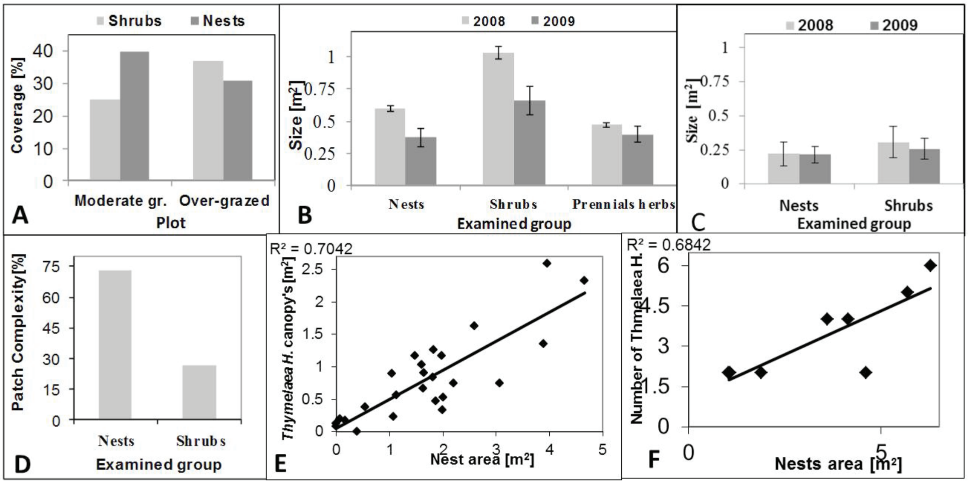

Fig. 1. The spatial impact of the different patches on micro topographic patterns of the ecosystem.

A. The coverage of 'nests' and 'shrubs' sub-plots in the moderate and over-grazed plots at 2009; B. The sizes of the different sub-plots in the moderate grazed plot at spring 2008 and 2009; C. The 'shrubs' and 'nests' sub-plots in the over grazed site at spring 2008 and 2009; D. The percentage of the 'complex' patches with relation to each 'examined group' at 2009; E. The effect of nests size on *Thymelaea hirsutae'* canopy size; F. The effect of nests' size on the number of *Thymelaea hirsutae'* shrubs.

Thin lines on columns represent +/- Standard errors.

*The number of patches containing herbaceous perennials was negligible in the overgrazed plot, so it is not presented

(Fig. 1A). There was almost 50% higher distribution of the nests than the calculated value for the shrub patches (40 and 30%, respectively). Additionally, the calculated nests sizes were much higher as compared to the 'perennials herbs' sub-plots in 2008 (in 2009 due to the drought there was a decrease in all patches with regard to the size as compared to 2008, but still the decrease in the nests size was lower than that at the shrub' patches, Fig. 1B). In the over-grazed site both nests and shrub patches maintained their sizes between the years (Fig. 1C). The ants' contribution to the biodiversity is evident from Fig 1D, whereas 75% of the nests appeared in complex patches as compared to only 25% in case of the shrubs. Positive correlation was found between the nest size and canopy area and between the number of *Thymelaea hirsutae* shrubs (Fig 1E and 1F).

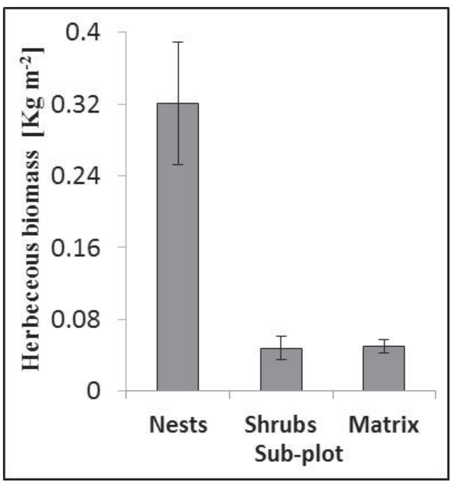

Fig. 2. The mean of herbaceous biomass in the different sub-plots, in the moderately grazed plot at spring 2010.

Thin lines above and below columns represent +/- Standard errors.

* - Statistical confidence (α) = 0.05

The annuals characteristics at the different sub-plots

Visual observations revealed that opposed to the diverse range of annuals in the 'shrubs' and 'perennial herbs'sub-plots, the nests are as were characterized mainly by Gramineae species *(Stipa capensis, Aegilops crass and A. Kotschy)*, while at the other sub-plots these species were only around 25% of the total annuals. These higher rates of cereals could indicate combined predation and dispersion scheme of a non–myrmechorous plant species [Retana et al. 2004]. Additionally, plants from the same species were more productive in the nests than in the other patches. Analysis of the total herbaceous biomass demonstrated significantly six fold difference between the nests and shrub sub-plots, or the matrix in favor of the nests (Fig. 2). As noted earlier, the analysis was done on active nests, yet, similar effects were found also in case of the abandoned ones [Farji-Brener 2005].

The soil quality parameters of the different sub-plots

The soil quality parameters were divided into fertility and hydrological ones (Fig. 3 and 4, respectively)

From Fig. 3 it could be noticed that with regard to all measured nutrients parameters, higher values were found in the nests than in the matrix soil. In the case of Potassium, even higher results were observed when compared to the 'shrubs' patches (Fig. 3C).

The highest field capacity values were measured at the 'shrubs' patches soil, middle values were found in the nests, and the lowest ones were in the Matrix. Regarding the water balance parameters, the high water capacity

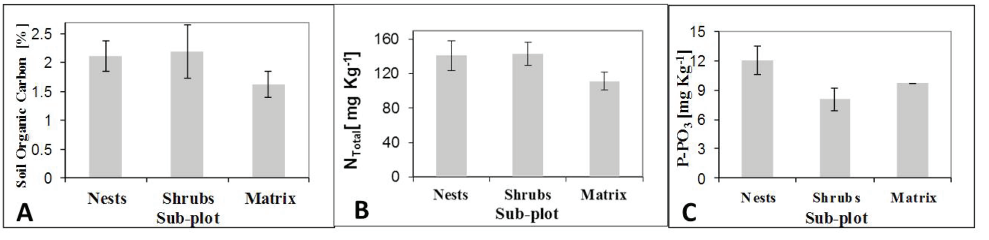

Fig. 3. Soil nutrients concentrations in the different micro-topographic groups moderately grazed plot at spring 2009.

A- Organic carbon; B- Nitrogen (total); C- Potassium.

Thin lines above and below columns represent +/- Standard errors.

* Measured in patches with stand-alone 'examined group'

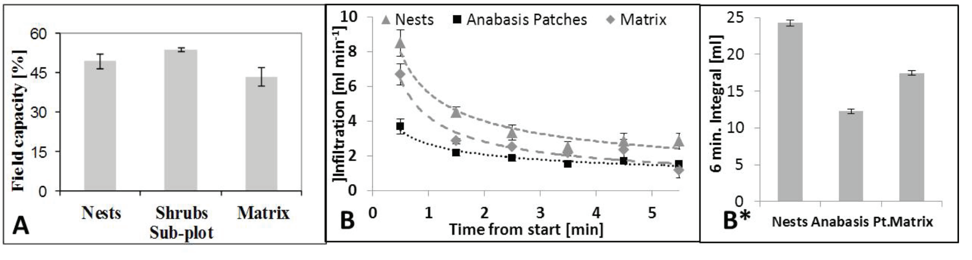

Fig. 4. The impact of the different groups on soil' water balance.

A- Field capacity, moderately grazed shrubland at spring 2009; B- Infiltration in the soil of nests, shrub patch and matrix micro-topographic groups at wadi Atir area, summer 2014. Thin lines above and below columns represent +/- Standard errors was found at the nest soil as compared to the bare soil (Fig. 4A). The infiltration rates were higher in the nests for the whole duration of the study as compared to the matrix, and even when compared to the *Anabasis setifera* shrub patches (Fig. 4B). These findings are adding new aspects to ones of Dostal et al. [2005] on *Lasius flavus*.

DISCUSSION

The study findings are an indication of the beneficial effects of ants' nests on the surrounding ecosystem much beyond being bio-indicators of the soil fertility [de Bruyn, 1999]. Quantification of the spatial-ecological impact was achieved using measurements on the number and sizes of the nests in the over- and moderately grazed sites by making an assumption that the spatial difference among these sites could indicate the ants' dynamic contribution during the transition from over grazing into moderately grazing regime. The comparison between the years hint on the climate dependency of this dynamics, whereas the comparison to the shrub patches gives attribution points to this dynamics. It is easily observed that at the over-grazed sites the number of nests was equal to the shrub patches, but after decreasing the grazing intensity, a massive propagation of the nest has occurred, which in turn contributed to the herbaceous growth at the nest boundaries. The *Messor* sp. resistance to drought stress in arid areas is exemplified by dolichoderine ants [Bestelmeyer1997] and is evident from the study by Pihlgren et al. [2010] on hilly topography and grazing in Europe. It is also evident from the preservation of the nests' numbers and sizes in the drought year (2009 compared to 2008, Fig. 1B), as only a small decrease of them was observed at the moderately grazed site (Fig. 1C). It has to be stressed that the nests sizes were estimated based on the ants' external soil disturbances (entrance holes, dumps, etc.), and not the total area of the nests rooms and channels, so the whole impact was assumed by us to be higher than the calculated one in the paper of Tschinkel [2004].

The documented correlations between the nests and the number of *Thymelaea hirsutae* shrubs, the nests and *Thymelaea hirsutae* canopy sizes, the nests and other species such as *Anchusa strigose* at the site of the study provided additional evidence for the beneficial impact of nests on the perennials, and not only on the annuals (mainly cereals as stressed earlier [Brown and Human, 1997]). Nevertheless, in case of several species such as *Pituranthos triradiatus*, the ants' activity was not observed under the shrub canopies. Such lack of association could be explained by the higher alkaloids concentrations of this plant that opposes nests' establishment [Hamada et al. 2004]. The ants positive impact on the arid ecosystem is also evident from the higher ratio of the nests in the complex patches, which indicate their better 'hospitality' rate with compare to the shrubs (Fig. 1 D) and the 'perennial herbs' group (data not shown) [Mor- Mussery et al. 2013]. One of the most limiting factors for the functioning of arid ecosystem is the water holding capacity, which is crucial in resisting the inconsistency patterns of the precipitation (with regard to their amounts, spreading and intensity) [Le'onard and Rajot 2001; Ward et al. 2000].

The presence of ants positively contributed to water holding of the soil since the infiltration rates and the field capacity were higher compared to the matrix. It has to be stressed, as opposed to the findings of the most former studies, which claim that the shrub patches reduce the runoff and increase the soil' water holding capacity [Ludwig et al. 2005], the measured infiltration rates of *Anabasis setifera* patch were lower than those of the matrix plots. Such a discrepancy could be explained by the dependence of the infiltration rates on the shrubs' root system which is tightly correlated to the local conditions [Mitchell et al. 1995]. Thus, the area which acts as water reservoir in arid areas has been increased in the presence of ants [Le'onard and Rajot 2001].

Our findings, concerning the higher nutrients concentrations in the nests, together with the increase in the water holding capacity are similar to those of Ludwig and Tongway [1995] on shrub patches. Their Sink-Source theory view on the impact of the shrub patches on the ecosystem fertility could be

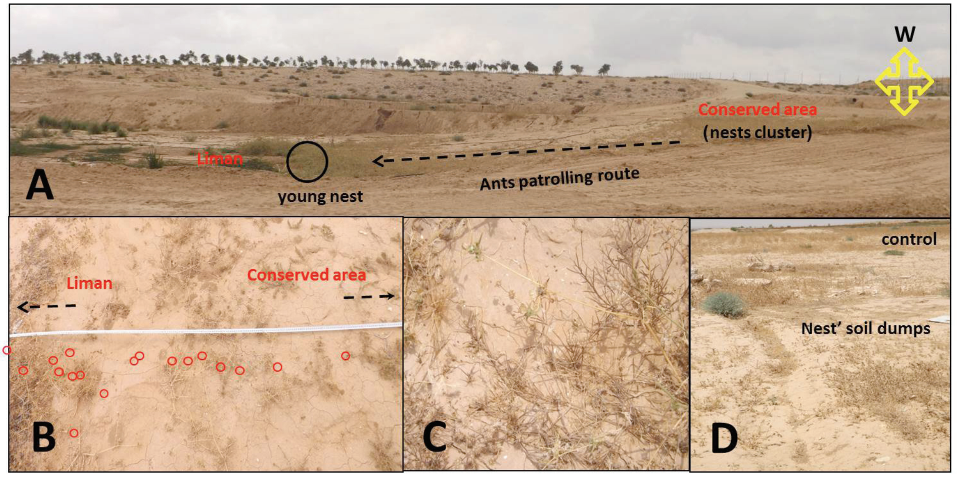

Fig. 5. The spatial effect of Messor sp. ants on area under conservation process (1 year from establishment), wadi Atir area, summer 2014.

A- Far view of the ants patrolling route from undisturbed plot to area after massive soil design (Liman); B- Close-up of the young nest inside the liman (The nest' entrance holes have 'X' shape, each edge as 1.9 m with soil dumps inside); C- Close up of the ants patrolling route (length 3.5m); D- Soil dumps from nest located in conserved area (one of the Byzantine farms)

also valid in case of the nests. In accordance to their theory, the nutrients that have been collected during the rain period from the surrounding sources to the nests, have gradually defused underground laterally from the nest areas to the surroundings after that. Thus, the nests were able to add 0.55 ton herbaceous biomass per hectare to the bare soil value, compared to addition of only 0.23 ton ha^{-1} herbaceous biomass in case of the shrub patches. Importantly, the bare soil is assumed to contain 0.8 ton ha^{-1} of herbaceous biomass. Additionally, the nests added to the bare soil values around 8.4 Kg ha^{-1} of nitrogen and 1.9 Kg ha^{-1} of organic carbon. The calculated values of nitrogen and organic carbon for bare soil in relation to root zone depth were 0.3 and 45.3 Kg ha^{-1}, respectively. Remarkably, similar results were obtained by the authors (unpublished data) on abandoned nests, which could hint to the long term effects of the *Messor* sp. nests, as documented on patches with dead shrubs [Jouquet et al. 2007]. Importantly, the samplings of the soil for the nutrient analyses were taken in the spring, so the results could be different in other seasons, due to the different dynamics of the nests and shrub patches [Zaady 2005].

Additional impact pattern of the nests on their surrounding ecosystem was observed after the heavy rain event in January 2013 (the rain amounts between the 8 and 10 of January in the site of study were 65mm, data from the farm owner) as soil dumps flooding from the nests to their sloped surrounding areas were observed. Specifically, in wadi Atir we found organic matter concentration of 14.4% in the soil dumps from nest in conserved area, compared to only 2.2% in adjacent conserved location (Fig. 6D). These results are in support of Cerda and Jurgensen [2008] findings, and add new aspect to the study of Wagner and Jones [2006] on the ants' impact on ecosystem fertility.

Observations from wadi Atir site at 2014 demonstrated the role of harvester ants' colonies spreading as the first step of degraded areas rehabilitation. This is achieved by the very presence of dense patrolling routes between source nests located at conserved plots and the daughter nests located at the degraded areas[Gordon 1987]. Fig. 5A-C presents patrolling route between the conserved and the degraded plots (created after massive groundwork). It has to be stressed that at the edges of the daughter nest we noticed in 2015 evidence of massive seedlings germination and annuals growth, much higher than at the surrounding area. These observations strengthen the findings from the main research site at Yatir farm about the dynamic of ants in area which was previously disturbed by over-grazing and which is now under conservation.

Based on the all former findings one can summarize the beneficial impact of ants on the arid ecosystem in the scheme of Fig. 6 which could be divided into several stages as follows:

Stage 1. Ants from the source nests settle in the young nests (Fig. 6A-C) [Gordon 1987; Schultheiss et al. 2010].

Stage 2. While the young nests in the areas exposed to over-grazing are minimally developed (Fig. 1C), in the moderately grazed areas the ants' activity creates patches enriched with nutrients (Fig. 4 A-C) and increased water holding capacity (Fig. 5).

Stage 3.The high nutrients concentrations together with the high water holding capacity encourage the primary production of annuals biomass which is an intermediate

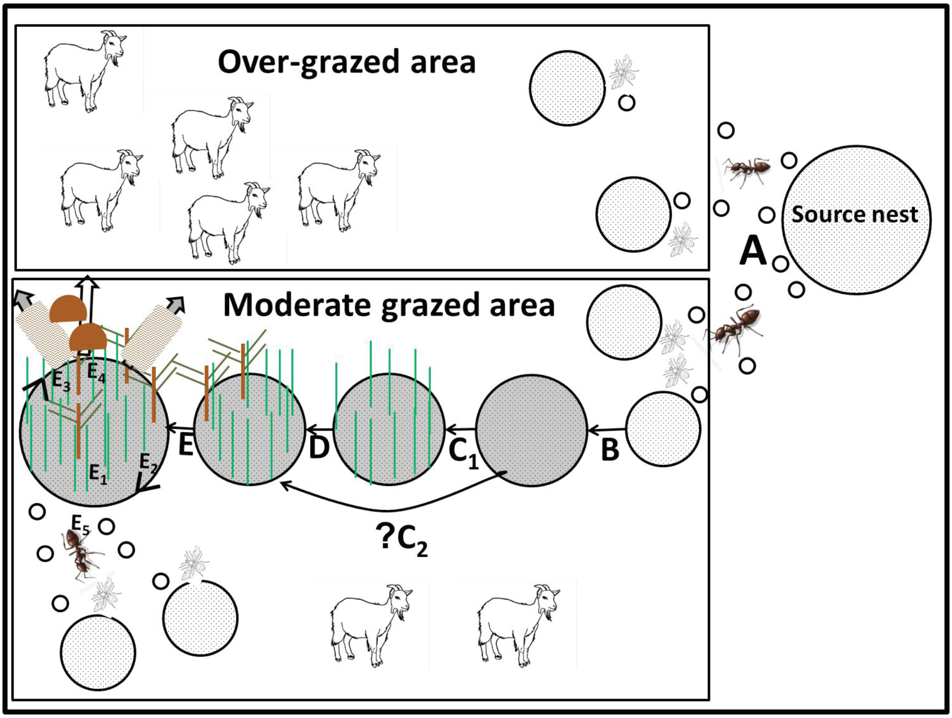

Fig. 6. The schematic representation of interactions between annuals, shrubs and nests in arid land.

A- Patrolling from the source nest and their establishments in new areas; B- In the moderately grazed area the nest absorb nutrients and water which cause its subsequent size enlargement (less common state in the overgrazed area); C1- The nest size enlargement and the higher nutrients concentrations encourage annuals establishment (mainly herbaceous species); C2- Based on Davidson and Morton [1984] findings there is higher germination and growth of several perennial species inside nests, even without the former settlement of the annuals, which may settle later on; D- The annuals growth encourages perennial germination and growth; E- Due to the ants activity and flora growth the patch' soil fertility has been increased (E1) and its size has been enlarged (E2), the surrounded ecosystem has been fertilized based on Ludwig and Tongway [1995] theory (E3) and based on the soil dumps spreading (E4), other ants are emissaries for patrolling (E5) (occur only in active nests).

step before perennials settlement (Fig. 2 and 3) [Farji-Brener and Ghermandi 2004].

Stage 4. Shrubs establishment.

Stage 5. Due to the shrubs establishment and their canopy enlargement, the ants' activity also increases in a positive feedback loop (Fig. 1B and 1E), along with the increase in the patch fertility (Fig. 1D). This leads to the rise in the fertility of the surrounding ecosystem according to the Source-Sink theory of Ludwig and Tongway [1995] and spreading of the nests' soil dumps (Fig. 6D). Parallel to these stages, ants continue to establish new young nests [Mailleux et al. 2003].

Optional stage related to several perennial species could be also defined. At this stage, the increase in the nutrients, moisture and the other nests dependent characteristics could encourage the germination and growth of perennials, even without the primary stage of annuals establishment and growth as demonstrated by Davidson and Morton [1984] on *Acacia* species.

It has to be stressed that these effects on the ecosystem are pronounced even in case of abandoned nests as found by our observations and based on Bieber et al. [2011] findings on leaf cutting ants' nests, which indicate the long-term effects of the nests on the ecosystem.

CONCLUSION

This paper indicates the positive impact of ants belonging to *Messor sp.* on arid ecosystem. This influence increased and spatially enlarged along the years, even in cases whereas the nests have been abandoned. These paper findings are emphasizing the need to avoid restricting the ants' activity, due to its tight correlation to the arid ecosystem functioning.

ACKNOWLEDGMENTS

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The paper is dedicated to Sigal Blay, my main source of inspiration for this study!

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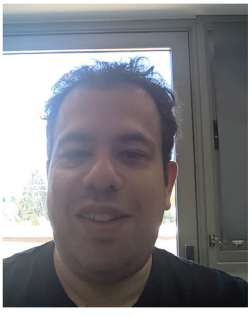

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CHANGES IN CLIMATIC CHARACTERISTICS AND CROP YIELD IN KWARA STATE (NIGERIA)

ABSTRACT. This paper assessed the vagaries of climatic elements on crop yield in Kwara State with a view to predicting the future climatic suitability level for selected crops in the state. Descriptive and infrential statistics analytical methods were used to examine the pattern of climatic elements for a period of 30 years. Analysis of variance was used to examine the variations in crop yield and also to determine whether or not significant differences in the harvests of the period under investigation. Correlation analysis was used to determine the relationship between climatic elements and crop yield while multiple regression analysis was used to determine the contribution of each climatic elements to crop yield. Time series analysis was used to project crop yield from 2014 to 2025. GAEZ model was adopted to determine the climatic suitability for the selected crops over time 1960 - 2050 and ArcGIS 10.3 software was used to produce the crop suitability maps. The result revealed that cassava, yam, maize and cowpea would be less suitable for production with the rate at which the climate is changing. The result also revealed that the climatic suitability level for cassava, yam, maize and cowpea would reduce drastically with time. The prediction shows severe impacts of changes in the selected climatic elements on both overall climatic suitability and crop the selected crops yield for by 2050.

KEY WORDS: Climatic elements, Climate change, Crop yield, Crop production, Crop suitability

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INTRODUCTION

According to IPCC 2009, agricultural production, including access to food, in many African countries is projected to be severely compromised. Projected reductions in yield in some countries could be as much as 50% by 2020, and crop net revenues could fall by as much as 90% by 2100, with small-scale farmers being the most affected. This would adversely affect food security in the continent and exacerbate malnutrition.

Researchers have shown that Nigeria is already being plagued with diverse ecological problems, which have been directly linked to the on-going climate change [Odjugo 2001; NEST 2003; Mshelia 2005; Ayuba et al. 2007]. However, the intent of this study is to assess the vagaries of climatic elements on crop yield in Kwara State with the view to predicting the future climatic suitability level of crop in the state. This study will specifically examine the pattern of climatic elements from 1985 –

2014; examine the variations in crop yields over a period (2002 – 2013); determine the relationship between climatic elements and crop yield; identify the contribution of each climatic elements to crop yield; map the current climatic suitability level of crops; project the crop yield from 2014 – 2025; and predict what the climatic suitability level would be by 2020 and 2050.

THE STUDY AREA

Kwara State is situated between latitudes 8°05′N and 10°05′N and longitudes 2°50′E and 6°05′E of the Greenwich meridian [Akpenpuun and Busari 2013]. It is one of the 36 states that make up the Federal Republic of Nigeria, Africa's most populous country. The State was created on May 27, 1967, when the Federal Republic of Nigeria was split into twelve states. It falls within the North-Central Geopolitical Zone of the country (Fig. 1). Kwara State consists of sixteen (16) Local Government Areas. Namely; Asa, Baruten, Edu, Ekiti, Ifelodun, Ilorin East, Ilorin South, Ilorin West, Irepodun, Isin, Kaiama, Moro, Offa, Oke-Ero, Oyun, and Pategi. Ilorin, the state capital is about 300kilometers away from Lagos and 500kilometers away from Abuja the federal capital of Nigeria [Tunde et al., 2013].

Kwara State landscape consists of a relatively flat and undulating land, lying at an altitude of between 265 and 480 meters above sea level [Ajibade, 2008]. The state is composed of Precambrian basement complex rocks – metamorphic and igneous rocks which is about 95% and sedimentary rock along the Niger River bank which is about 5% of the total area. According to Food and Agricultural Organization [FAO, 2003], Kwara State soils are classified into ferric luvisols, district nitosols, fluvisols and lithosols.

Kwara State lies within a region described as humid tropical climate. The Tropical Maritime air mass from the Atlantic Ocean is prevalent from March to October, while the Tropical Continental air mass from the Sahara desert takes over from November to February (Olaniran, 2002 adapted from [Jimoh and Adeoye, 2011]). The annual rainfall ranges from 800 mm to 1500 mm [Oladimeji et al., 2014] with minimum temperature ranging from 21.1^{0}C to 25^{0}C while average

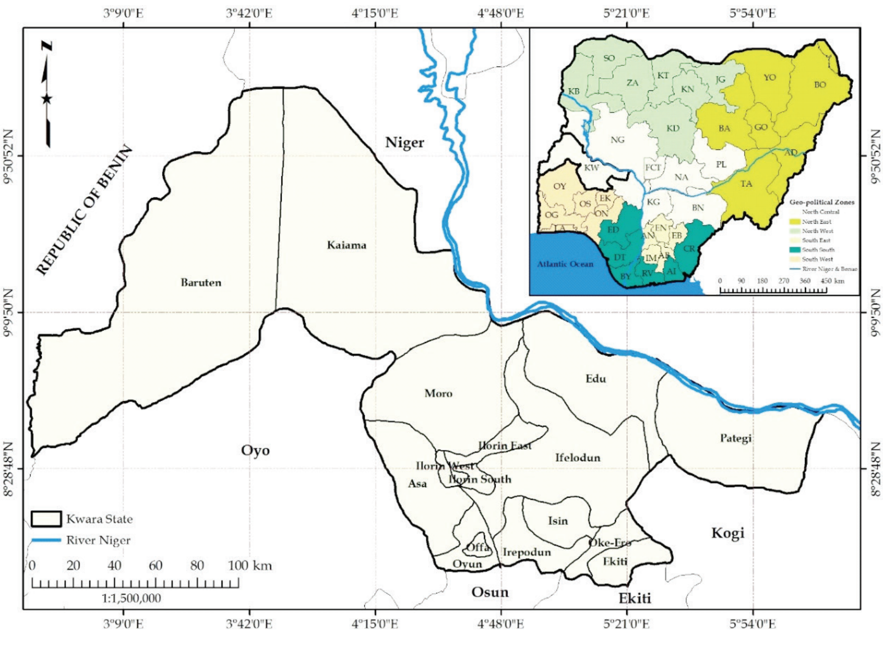

Fig. 1. Map of Kwara State Showing the Sixteen Local Government Areas Inset: Map of Nigeria Showing the Six Geo-political Zones

maximum temperature ranges from 30⁰C to 35⁰C [Adesiji et al., 2012]. Relative humidity varies seasonally ranging from 75% to 80%. The daytime is sunny and the sun shines brightly for about 6.5 to 7.7 hours daily from November to May [Akpenpuun and Busari, 2013].

The natural vegetation cover of Kwara State belongs to the tropical savannah which comprises of derived savannah and guinea savannah. The derived savannah (rainforest) is found in the southern part of the state while the guinea savannah (woodland) is to the north.

According to the 2006 census reports, the population of Kwara State stood at 2.37 million consisting mainly of Yoruba, Nupe, Fulani and Baruba ethnic groups. The figure was projected with the annual growth rate of 3.2 percent to be 3.14 million in 2015 [National Population Commission 2015]. The average population density of the state as at 2015 is about 95 people per square kilometer. The three major religious faiths in Nigeria – Islam, Christianity and traditional, coexist within the state.

The population of the state is predominantly farmers that specialized in arable crops. Crops such as maize, cowpea, yam, cassava, groundnut, tomato, sorghum, millet, and sweet potato among others are cultivated on upland areas while rice cultivation is done on the lowland and floodplain of river Niger [KWADP, 2010]. Agriculture is the main productive economic activity in the state as farmers account for about 70% of the total population. It has about 260,528 farm families [KWADP, 2010] and approximately 25% of the land area of Kwara State (32,500 square kilometers) is used for farming.

MATERIALS AND METHODS

The descriptive analytical method was used to examine the pattern of climatic elements for a period of 30 years (1985 – 2014). Analysis of variance (ANOVA) was used to examine the variations in crop yield and also to determine whether or not significant differences exist between the harvests of the period under investigation. Correlation analysis was used to determine the relationship between climatic elements and crop yield while; multiple regression analysis was used to determine the contribution of each climatic elements to crop yield. Time series analysis was used to project crop yield from 2014 to 2025, GAEZ model was adopted to determine the climatic suitability (%) for the selected crops for 1960-1990, 1990–2020 and 2020–2050 and ArcGIS 10.3 software was used to produce the crop suitability maps.

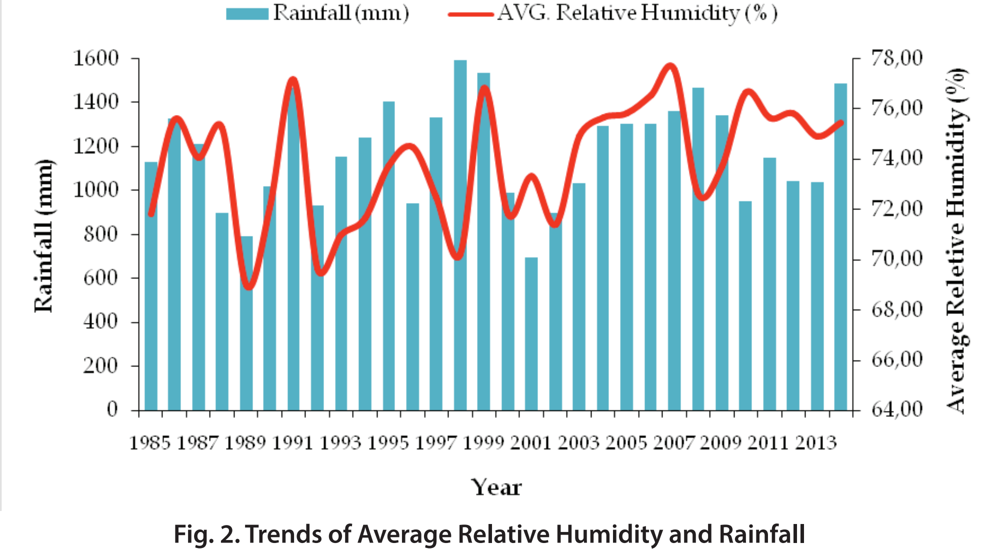

Fig. 2. Trends of Average Relative Humidity and Rainfall
Source: Researchers' computation, 2016

Table 1. Climatic Data for 1985 - 2014

Year	Rainfall (mm)	AVG. Relative Humidity (%)	Temperature (max)	Temperature (min)
1985	1133.3	71.83	32.49	21.68
1986	1328.4	75.58	31.88	21.59
1987	1213.7	74.08	33.10	21.99
1988	898.9	75.25	32.23	21.88
1989	794.6	69.00	32.19	20.69
1990	1020.1	72.08	32.42	21.77
1991	1468.4	77.17	31.76	21.73
1992	931.6	69.67	31.95	21.14
1993	1157.9	71.00	31.73	21.01
1994	1242	71.67	31.93	21.27
1995	1409.2	73.75	32.06	21.35
1996	945.3	74.50	32.38	21.51
1997	1334.4	72.50	31.87	21.48
1998	1595.5	70.25	32.41	22.04
1999	1539.3	76.83	31.88	20.79
2000	990.3	71.83	32.72	22.24
2001	697.1	73.33	33.18	21.63
2002	902.3	71.42	32.68	21.82
2003	1033.5	74.92	32.35	22.08
2004	1294	75.67	32.27	21.98
2005	1305.9	75.83	32.42	22.25
2006	1303.8	76.58	32.23	21.67
2007	1361.4	77.58	32.50	21.42
2008	1470.5	72.67	32.15	21.59
2009	1342.7	73.75	31.29	21.03
2010	953.6	76.67	32.33	21.19
2011	1150.8	75.67	32.27	21.63
2012	1046.3	75.83	32.42	21.82
2013	1040.6	74.92	33.03	22.03
2014	1490.5	75.48	32.92	22.13

Source: Nigeria Meteorological Service (NIMET) – Ilorin, 2016.

RESULTS AND DISCUSSION

The pattern of the climatic elements – rainfall, average relative humidity, minimum temperature and maximum temperature of Kwara State for the period 1985 – 2014 is presented in Table 1

For a better visual and comprehension of the pattern of the selected climatic elements, the results in Table 1 are hereby represented graphically in Figures 2, 3 and 4. Fig. 2 reveals that there are variations in the climatic elements tested. It is observed that rainfall amount fluctuates through the years under study with the highest value 1595.5mm recorded in 1998 and the lowest value 697.1mm in 2001. Average rainfall amount from 1985 to 2014 was 1179.86mm, therefore the values recorded in the years 1985, 1988, 1989, 1990, 1992, 1993, 1996, 2000 - 2003, and 2010 - 2013 are below the average. This can be regarded as years with low rainfall amount. Values for 1986, 1987, 1991, 1994, 1995, 1997, 1998, 1999, 2004, 2005 - 2009 and 2014 are above the average value and are said to have high rainfall amount.

Average relative humidity also experienced fluctuations over the year under study (Fig. 2) with the highest value in 2007 (77.58%) and lowest value in 1989 (69%). This is in conformity with the findings of Jimoh and Adeoye [2011] and [Tunde et al., 2011] where they also observed that there are variations in Kwara State's rainfall and average relative humidity over the years.

Figures 3 and 4 clearly show the fluctuations in minimum and maximum temperature over a period of 30 years (1985 – 2014). The highest minimum temperature was recorded in the year 2005 (22.25°C) while the lowest was recorded in 1989 (20.69°C) (see Fig. 3). The maximum temperature has been increasing and was highest in the year 2001 (33.18°C) and lowest in year 2009 (31.29°C) (see Fig. 4). The computed R^2=0.0436 and R^2=0.0417 in minimum temperature (Fig 3) and maximum temperature (Fig 4) respectively show an upward of temperatures in the study area. The computed R^2 implies that minimum temperature increased at the rate of 4.36%, while maximum temperature was 4.17%. The minimum temperature increased faster than the maximum temperature.

Table 2 presents the yield of the selected crops in Kwara State for the year 2002-2013. The table reveals that there are variations in the yield of the selected crops. The crops are of two types: Tubers – Cassava and Yam and Grains – Maize and Cowpea. The table revealed that tuber crops are produced more than grains in the study area. However, the rate of change in crop production yield in the four crops varies (negative and positive) over the years.

Fig. 5 shows the trend of the yield. Cassava which is the leading crop has the highest yield in the year 2013 (17.48), lowest in 2004 (12.21), increase steadily from 2009 to 2013. Yam has its highest output in 2013 (14.45) and lowest output in 2003 (10.86),

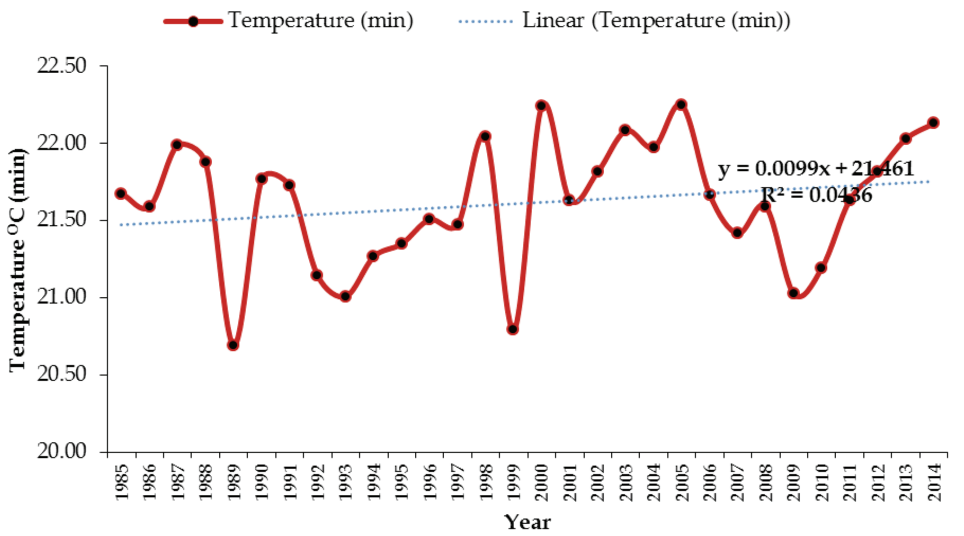

Fig. 3. Trends of Annual Minimum Temperature

Source: Researchers' computation, 2016.

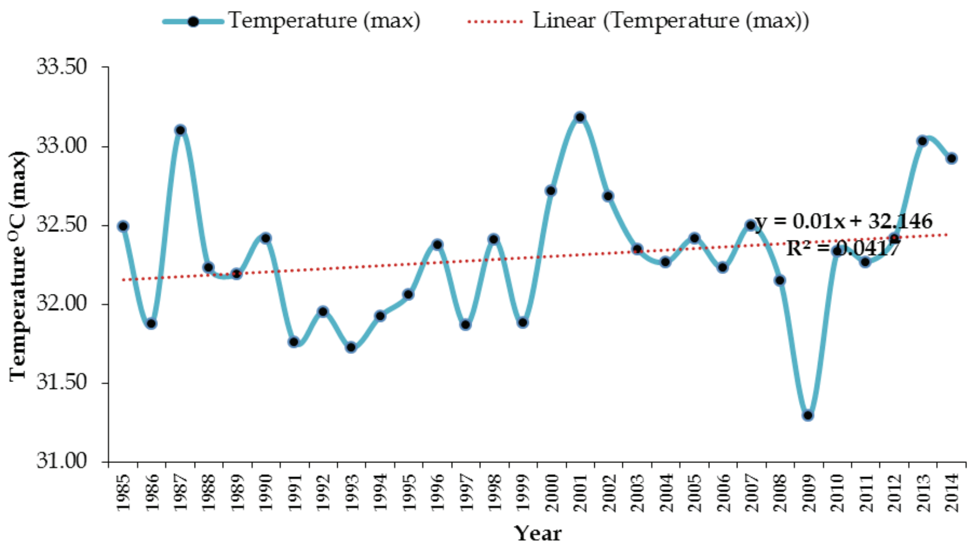

Fig. 4. Trends of Annual Maximum Temperature

Source: Researchers' computation, 2016.

Table 2. Crop Yield (Tons/Ha) in '000 (2002 – 2013)

Year	Tuber				Grain			
	Cassava	%	Yam	%	Maize	%	Cowpea	%
2002	12.94	0.00	12.33	0.00	1.3	0.00	0.14	0.00
2003	12.56	-2.94	10.86	-11.92	1.47	13.08	0.17	21.43
2004	12.21	-2.79	11.7	7.73	1.25	-14.97	0.13	-23.53
2005	12.46	2.05	11.63	-0.60	1.35	8.00	0.25	92.31
2006	15.28	22.63	11.85	1.89	1.58	17.04	0.26	4.00
2007	16.99	11.19	11.66	-1.60	1.37	-13.29	0.44	69.23
2008	17.14	0.88	12.46	6.86	1.43	4.38	0.4	-9.09
2009	15.97	-6.83	12.46	0.00	1.5	4.90	0.45	12.50
2010	16.48	3.19	12.53	0.56	1.47	-2.00	0.43	-4.44
2011	16.8	1.94	13.14	4.87	1.49	1.36	0.46	6.98
2012	16.98	1.07	13.83	5.25	1.58	6.04	0.65	41.30
2013	17.48	2.94	14.45	4.48	1.59	0.63	0.91	40.00

Source: Kwara State Agricultural Development Project (KWADP), 2016.

while there is no much variation in the output of maize and cowpea. The changes were attributed to variations in the climatic condition of the study area.

The result of the descriptive statistics of the yield of selected crops is presented in Table 3. The table shows that the annual average yield was 6.68 in 2002, 6.27 in 2003, 6.32 in 2004 and 6.42 in 2005. However, the annual average yield was not less than 7.24 from 2006 up till 2011, this rose to 8.26 and 8.61 in 2012 and 2013 respectively. Since 2007 the annual average has been above the cumulative average (7.38) for the year under study (Table 3).

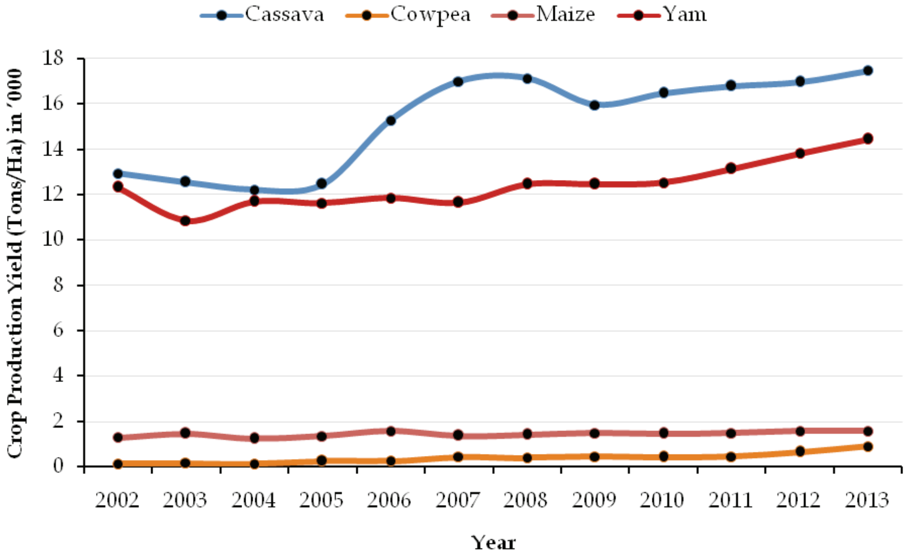

Fig. 5. Line Graph Showing Crop Production Yield (2002 - 2013)

Source: Researchers' computation, 2016.

The result of the Analysis of Variance is presented in Table 4. It is clear that the years of crop production has no effect on the crop yields (F (11, 36) = 0.43, p>.05). The result revealed that there was no significant variation in the crop yields for the years under study (2002 to 2013).

Table 5 reveals the relationship between climatic data and crop yield. There was no

Table 3. Descriptive Statistical Results of Crop Yield in 2002 - 2013

Year	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
2002	4	6.678	6.900	3.450	-4.30	17.66	0.14	12.94
2003	4	6.265	6.348	3.174	-3.84	16.37	0.17	12.56
2004	4	6.323	6.523	3.262	-4.06	16.70	0.13	12.21
2005	4	6.423	6.517	3.258	-3.95	16.79	0.25	12.46
2006	4	7.243	7.453	3.727	-4.62	19.10	0.26	15.28
2007	4	7.615	8.057	4.028	-5.21	20.44	0.44	16.99
2008	4	7.858	8.252	4.126	-5.27	20.99	0.40	17.14
2009	4	7.595	7.789	3.895	-4.80	19.99	0.45	15.97
2010	4	7.728	8.002	4.001	-5.00	20.46	0.43	16.48
2011	4	7.973	8.228	4.114	-5.12	21.06	0.46	16.80
2012	4	8.260	8.359	4.179	-5.04	21.56	0.65	16.98
2013	4	8.608	8.590	4.295	-5.06	22.28	0.91	17.48
Total	48	7.380	6.716	0.969	5.43	9.33	0.13	17.48

Source: Researchers' computation, 2016.

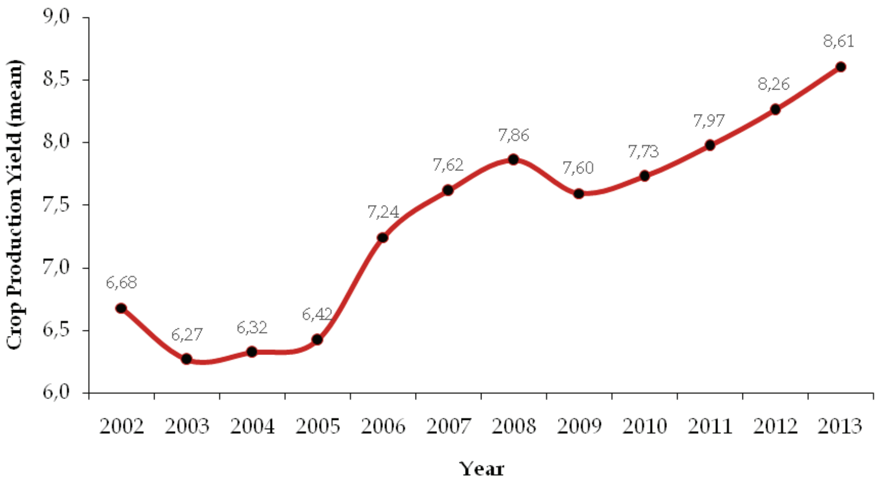

Fig. 6. Line Graph Showing the Mean Crop Yield (2002 - 2013)
Source: Researchers' computation, 2016.

Table 4. Statistical Variation in Crop Yield

	Sum of Squares	*df*	Mean Square	F	Sig.
Between Groups	27.493	11	2.499	.043	>.05
Within Groups	2092.551	36	58.126		
Total	2120.044	47			

Source: Researchers' computation, 2016.

significant association between rainfall and cassava (r=0.107), cowpea (r=-0.127), maize (r=-0.155). This indicates that increase or decrease in the rainfall did not significantly relate to increasing or decrease in the yield of cassava, cowpea, and maize. Rainfall has a negative relationship with yam (r=-0.311), the result implies that increase in rainfall significantly related to decrease or poor yield of yam.

The result further revealed that AVG relative humidity has no significant positive relationship with cassava (r=0.189), cowpea (r=0.168) and yam (r=-0.103). This implies that increase or decrease in AVG relative humidity did not significantly relates to increase or decrease in the yield of cassava, cowpea and yam. However, there was significant positive and weak relationship between AVG relative humidity and maize

Table 5. Correlation of Climatic Elements and Crop Yield

Crop	Rainfall (mm)	AVG. Relative Humidity (%)	Temperature (max)	Temperature (min)
Cassava	.107	.189	-.011	-.552
Cowpea	-.127	.168	.250	-.151
Maize	-.155	.214	-.034	-.190
Yam	-.311	-.103	.290	-.076

***Correlation is significant at the 0.05 level (2-tailed).**
Source: Researchers' computation, 2016.

(r=0.214), indicating that increase in AVG relative humidity significantly relates to high yield of maize. Meaning that the high AVG relative humidity will lead to high yield of maize

Furthermore, maximum temperature have no significant positive relationship with cassava (r=-0.011), and maize (r=-0.034), indicating that increase or decrease in maximum temperature did not significantly relates to increase or decrease in the crop yield. The result of the analysis further reveals that there was a significant positive though weak relationship between maximum temperature and yield of cowpea (r=0.250), and yam (r=0.290). The result indicates that maximum temperature is needed for good yield of cowpea and yam. The result also shows that minimum temperature has an inverse and a weak relationship with maize (r=-0.190). This implies that increase in the minimum temperature leads to a significant decrease in the yield of maize.

Multiple Regression analysis was employed to determine the percentage contribution of each of the climatic elements to crop yield (Table 6). The regression equation used for this analysis is; $Y = a+b_1x_1+b_2x_2+b_3x_3+b_4x_4+e$, where Y = Crop yield, X_1 = Rainfall, X_2 = Relative Humidity, X_3 = Minimum Temperature, X_4 = Maximum Temperature, e = error term, a = intercept i.e. the value of 'y' when x_1x_2 - - - - - x_n are zero b_1b_2 - - - - - , b_n = gradient of the multiple regression line.

The regression analysis computed for the crops (Table 6) revealed that cassava, cowpea, maize, and yam have the following coefficient of determination 0.55, 0.22, 0.13 and 0.23 respectively. The result accounted for 55%, 22%, 13% and 23% of the change observed in the variance of the crops. The result indicates that 45%, 78%, 87% and 77% of the differences in cassava, cowpea, maize and yam can be explained by other factors that were not included in the model. By implication, the climatic condition has a significant influence on cassava. This is in line with Olanrewaju [2010] findings in her study on the effect of Climate on Yam Production in Kwara State, Nigeria which established that climatic elements plays crucial roles in the productivity rate of yam in Kwara State. Similarly, Tunde, et al, [2011] in their study on the effects of climatic variables on crop production in Pategi L.G.A., Kwara State reported that variation in rainfall, relative humidity, maximum and minimum temperature have a great effect on crop yield.

Time series analysis was used to project the obtained crop yield data (2002-2013) from Kwara State Agricultural Development Project (KWADP) office in Ilorin. The result of the projection (2014 - 2025) reveals that there would be a steady increase in cowpea yield, while cassava, maize, and yam would experience variations over the projected years (see Table 7). The result also follows the pattern of the data used for the projection. For example, the crop yield for cassava, maize and yam drop in 2009 which is the 8th year and the same trend was observed in the year 2021 (also the 8th year). The result obtained in both years (2009 and 2021) are less than their previous years (2008 and 2020). The result is illustrated in Fig. 6. It must however be noted that the projection was done based the obtained crop yield data from KWADP and therefore any change in the inputs and management levels, climatic condition and

Table 6. Regression of Climatic Elements and Crop Yield

Crop	R	R^2	Standard Error	F	P-Value
Cassava	0.740	0.547	1.77276	2.115	.182
Cowpea	0.474	0.224	0.25035	0.506	.734
Maize	0.358	0.128	0.13090	0.257	.896
Yam	0.479	0.229	1.10700	0.520	.725

Source: Researchers' computation, 2016.

Table 7. Projected Crop Yield for 2014-2025

Year	Cassava	Cowpea	Maize	Yam
2014	14.23	1.54	1.43	13.56
2015	13.82	1.87	1.62	11.95
2016	13.43	1.43	1.38	12.87
2017	13.71	2.75	1.49	12.79
2018	16.81	2.86	1.74	13.04
2019	18.69	4.84	1.51	12.83
2020	18.85	4.40	1.57	13.71
2021	17.57	4.95	1.65	13.71
2022	18.13	4.73	1.62	13.78
2023	18.48	5.06	1.64	14.45
2024	18.68	7.15	1.74	15.21
2025	19.23	10.01	1.75	15.90

Source: Researchers' computation, 2016.

so on could affect the projected yields (Fig. 7).

CROP CLIMATIC SUITABILITY LEVEL

Climatic suitability for the crop is the level of current climatic characteristics that permit successful crop growth. This entails matching crop/LUT requirements with the prevailing climatic conditions. GAEZ model was used to produce the suitability maps in this study using the combined climate related constraints. The model provides information on the climate-related constraints affecting crop yields. These constraints include temperature, moisture, and yield due to pests, diseases and soil.

In GAEZ, three generic levels of agricultural practices are defined: low, intermediate, and high levels. However, the intermediate level was used for this study, because it is believed

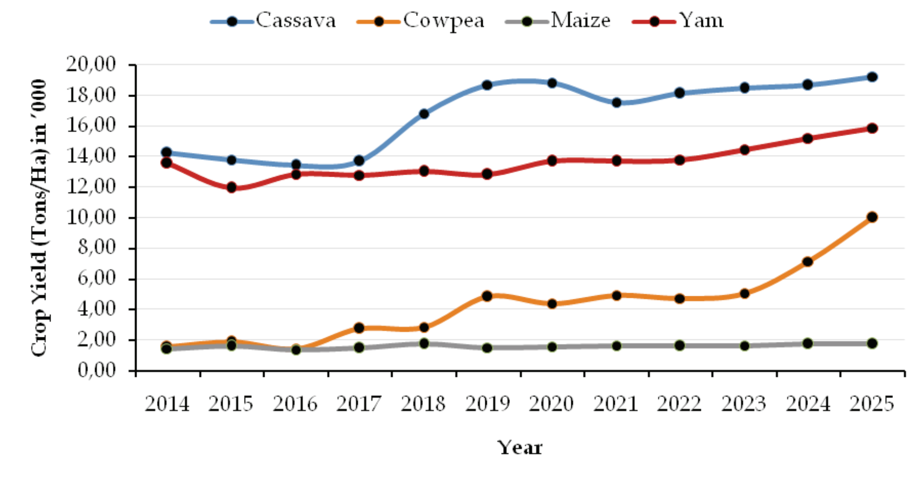

Fig. 7. Line Graph Showing the Projected Crop Yield (2014 - 2025)
Source: Researchers' computation, 2016.

to be the most appropriate level of agricultural practice to use in this type of research. Under an intermediate level, the farming system is partly market oriented. Production for subsistence plus commercial sale is a management objective. Production is based on improved varieties, on manual labor with hand tools and/or animal traction and some mechanization, is medium labor intensive, uses some fertilizer application and chemical pest disease and weed control, adequate fallows and some conservation measures. The model has been applied considering the 30-year period (climatic cycle) i.e. the baseline period 1960-1990, 1990–2020 and 2020-2050.

The climate data from the Canadian Centre for Climate Modeling and Analysis (CCCma) Coupled Global Climate Model (CGCM2) of IPCC (Intergovernmental Panel on Climate Change) SRES (Special Report on Emissions Scenarios) A2 scenarios was adopted in the model used. CGCM2 is the second generation coupled global climate model. The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing the global population. Economic development is primarily regionally oriented, and per capita economic growth and technological change are more fragmented and slower than in other scenarios [FAO/IIASA, 2011].

Figures 8, 9 and 10 show Kwara state climatic suitability maps of cassava for years 1961-1990, 2020 and 2050 respectively. The suitability values are given in percent (0-100) i.e. > 0.95, 0.9-0.95, 0.8-0.9, 0.7-0.8, 0.6-0.7, 0.5-0.6, 0.4-0.5, 0.3-0.4, 0.2-0.3, < 0.2 which is 95-100%, 90-95%, 80-90%, 70-80%, 60-70%, 50-60%, among others. The result reveals that cassava suitability decreases with time as a result changes in the climatic elements; rainfall, relative humidity, minimum temperature and maximum temperature. Cassava is 70-100% suitable in the base period (Fig. 8) while some parts of the state fell below 70% in years 2020 and 2050 (Figs 9 and 10).

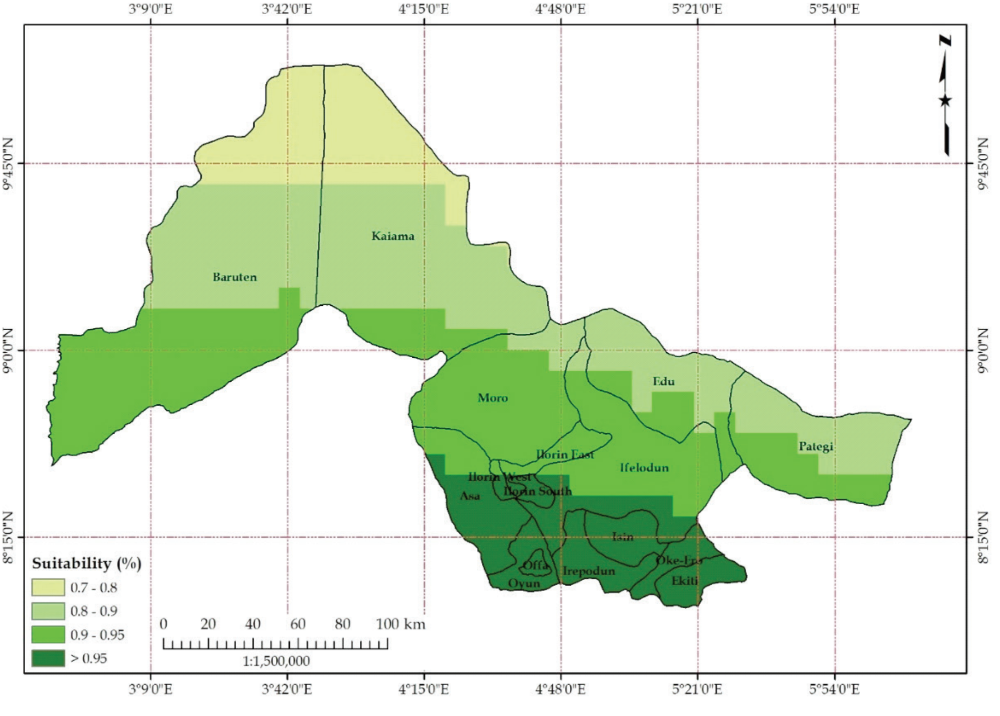

Fig. 8. Cassava Suitability Map for Baseline Period (1961-1990)

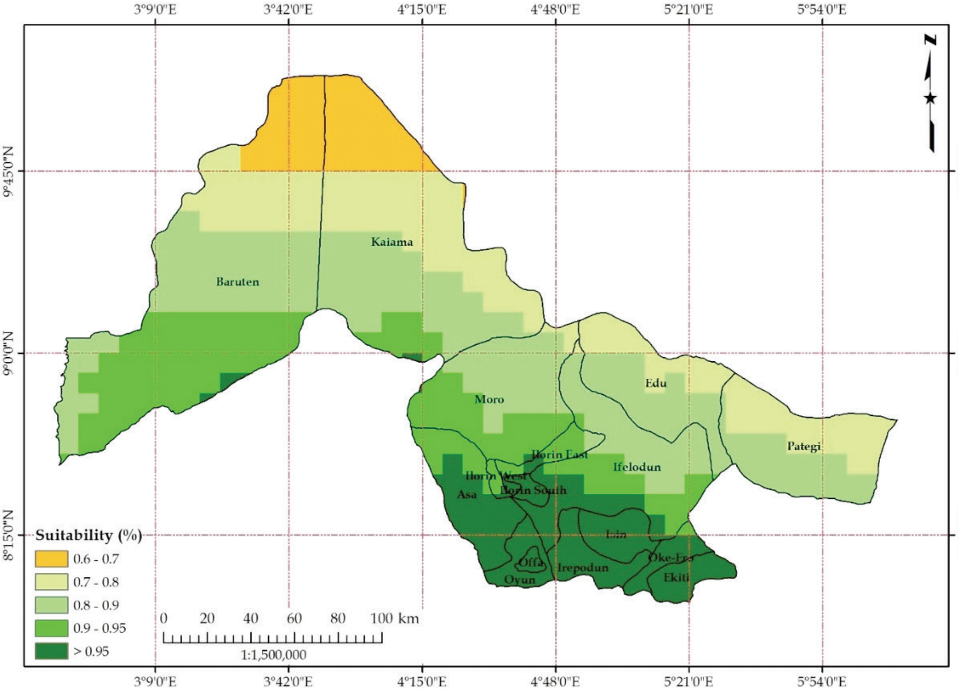

Fig. 9. Cassava Suitability Map for 2020

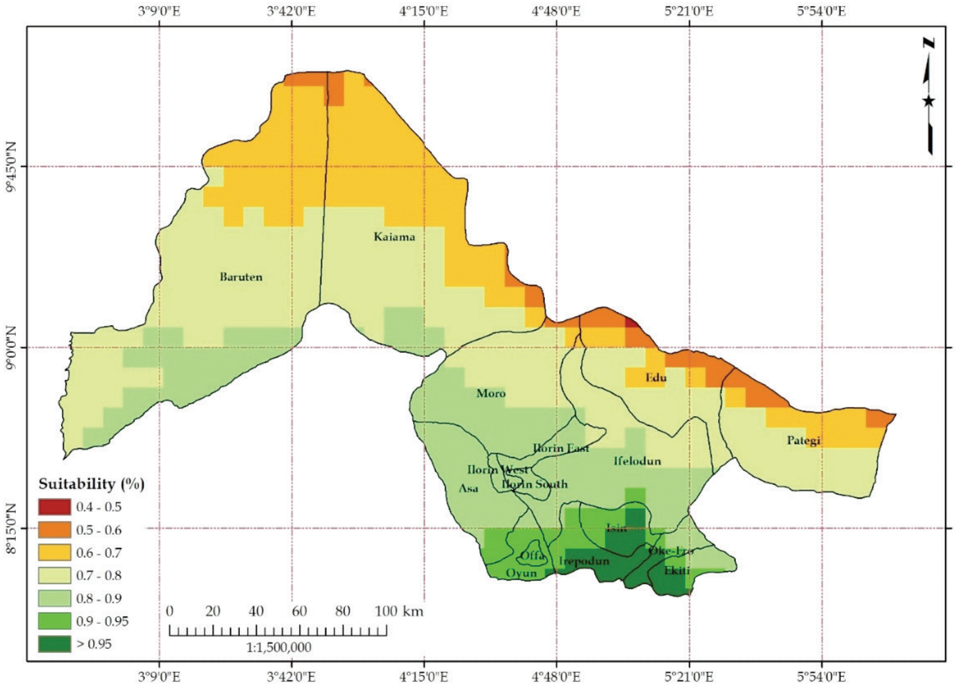

Fig. 10. Cassava Suitability Map for 2050

Figures 11, 12 and 13 show Kwara state climatic suitability maps of cowpea for years 1961-1990, 2020 and 2050 respectively. The suitability values are given in percent (0-100). The result reveals that cowpea is 95-100% suitable for years 1960-1990 and 2020. However, it reduces to 90-95% in parts of Kaiama, Moro, Edu and Pategi Local Governments areas of the state in year 2050 (Fig. 13).

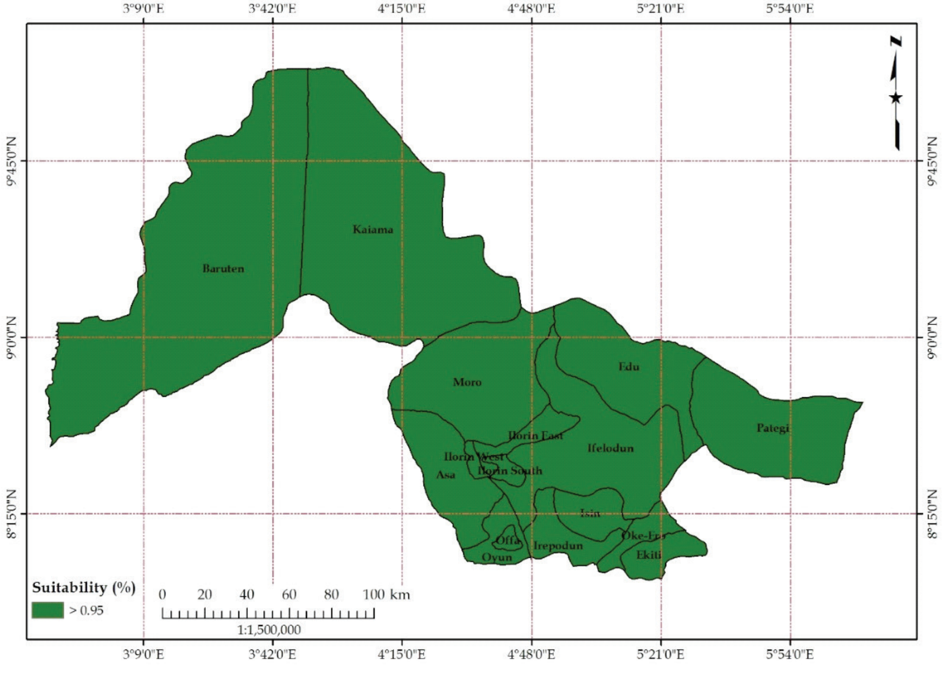

Fig. 11. Cowpea Suitability Map for Baseline Period (1960-1990)

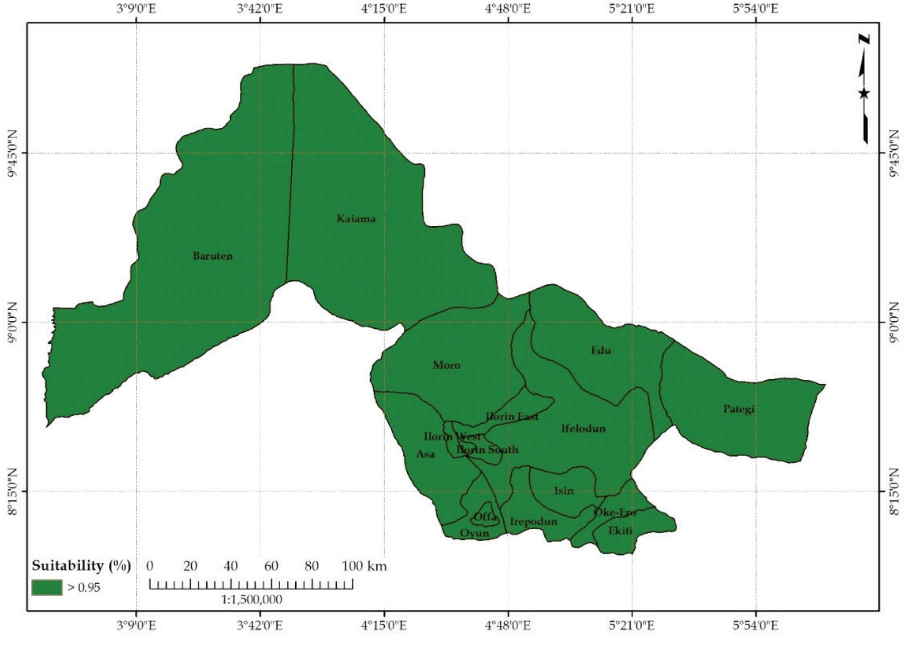

Fig. 12. Cowpea Suitability Map for 2020

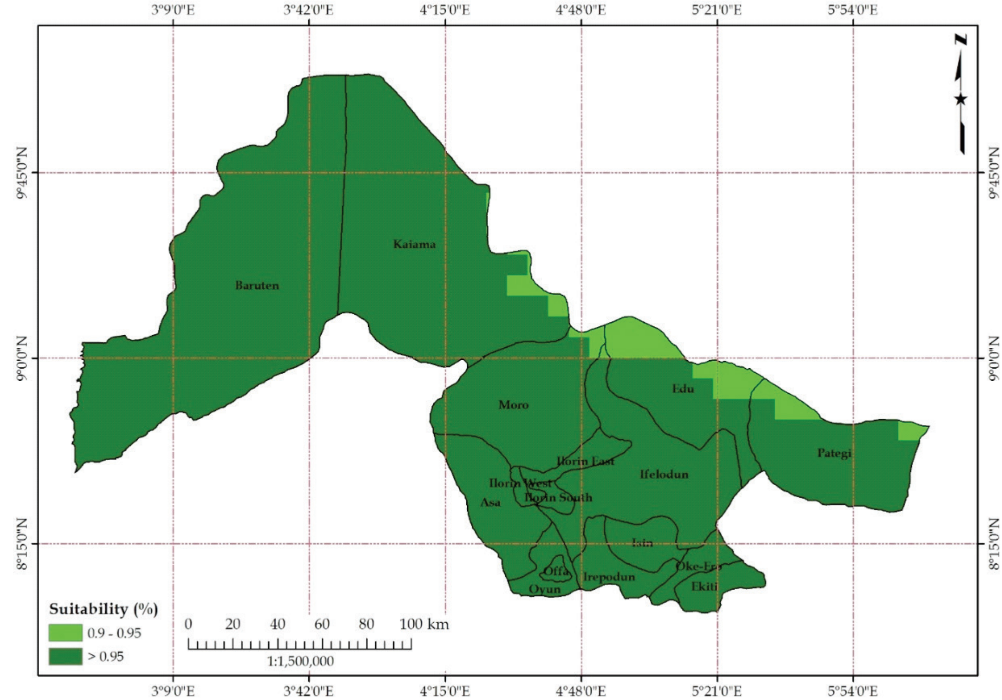

Fig. 13. Cowpea Suitability Map for 2050

Figures 14, 15 and 16 show Kwara state climatic suitability maps of maize for years 1961-1990, 2020 and 2050 respectively.

The result reveals that maize is 80-100% suitable for years 1960-1990, 2020 and 2050.

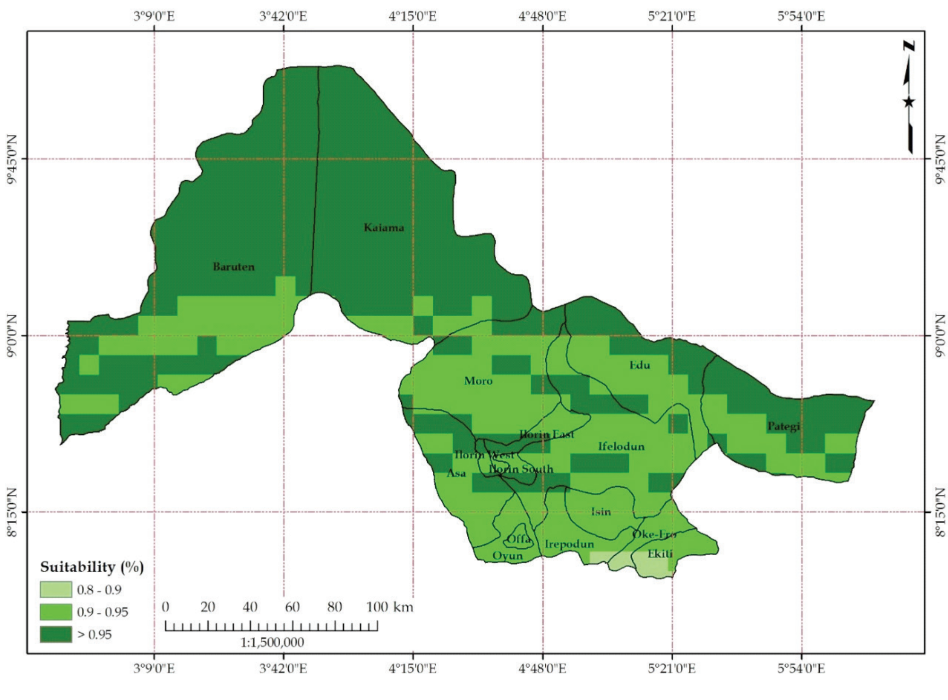

Fig. 14. Maize Suitability Map for Baseline Period (1960-1990

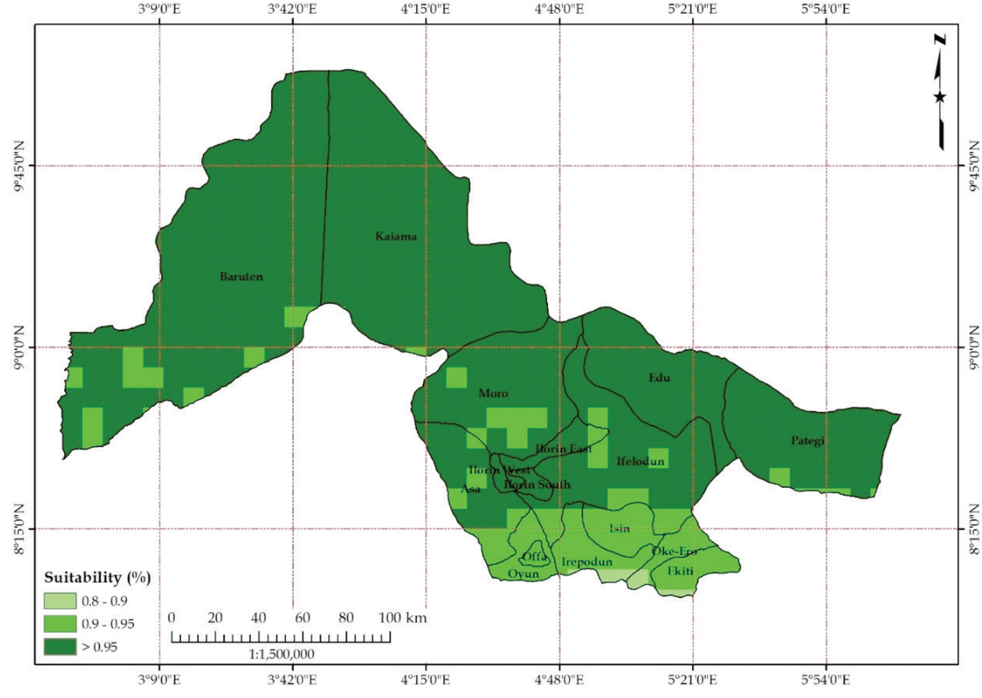

Fig. 15. Maize Suitability Map for 2020

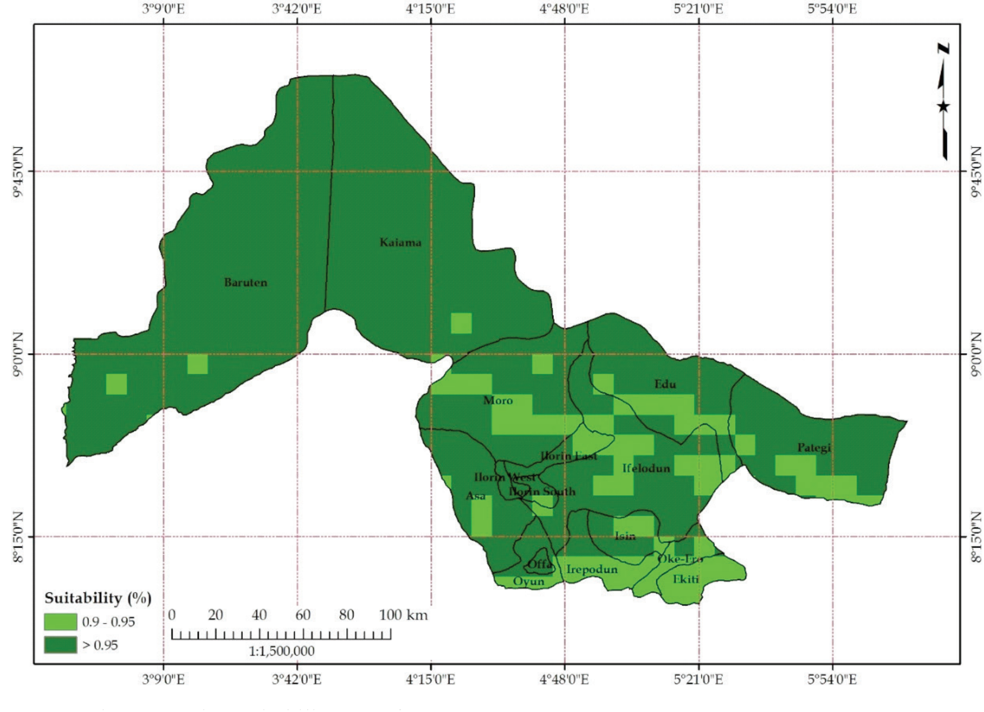

Fig. 16. Maize Suitability Map for 2050

Figures 17, 18 and 19 show Kwara state climatic suitability maps of yam for years 1961-1990, 2020 and 2050 respectively. The result reveals that maize is 70-100% suitable for years 1960-1990 and 2020. However, parts of Kaiama, Moro, Edu and Pategi Local Governments areas of the state would not be suitable for yam production by year 2050 (Fig. 19).

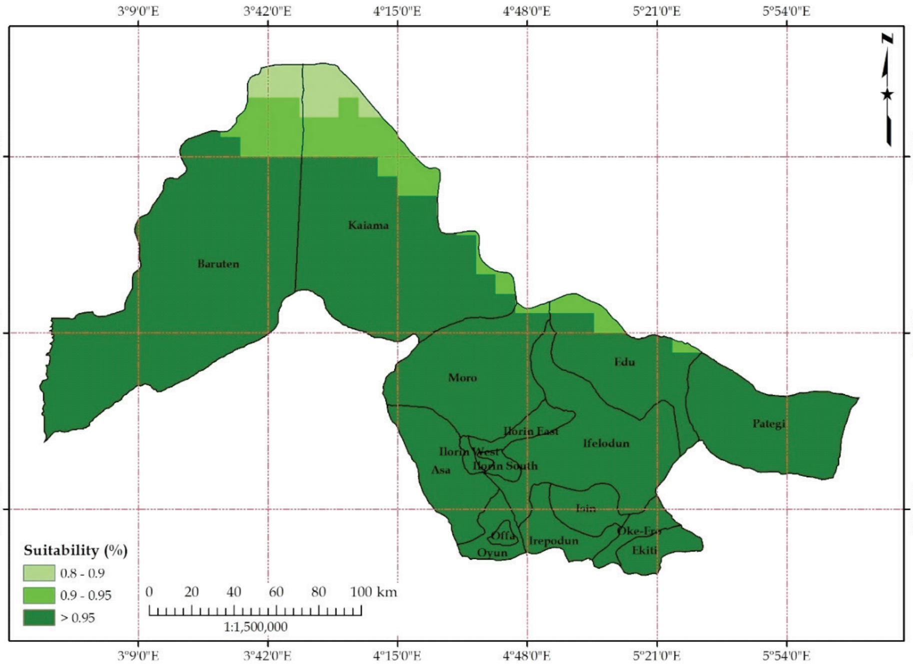

Fig. 17. Yam Suitability Map for Baseline Period (1960-1990)

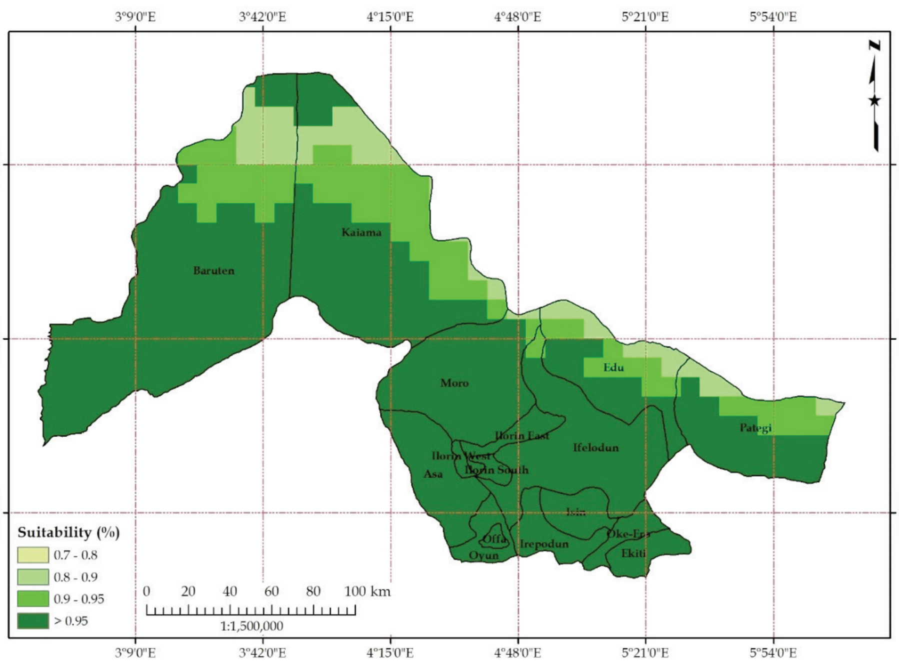

Fig. 18. Yam Suitability Map for 2020

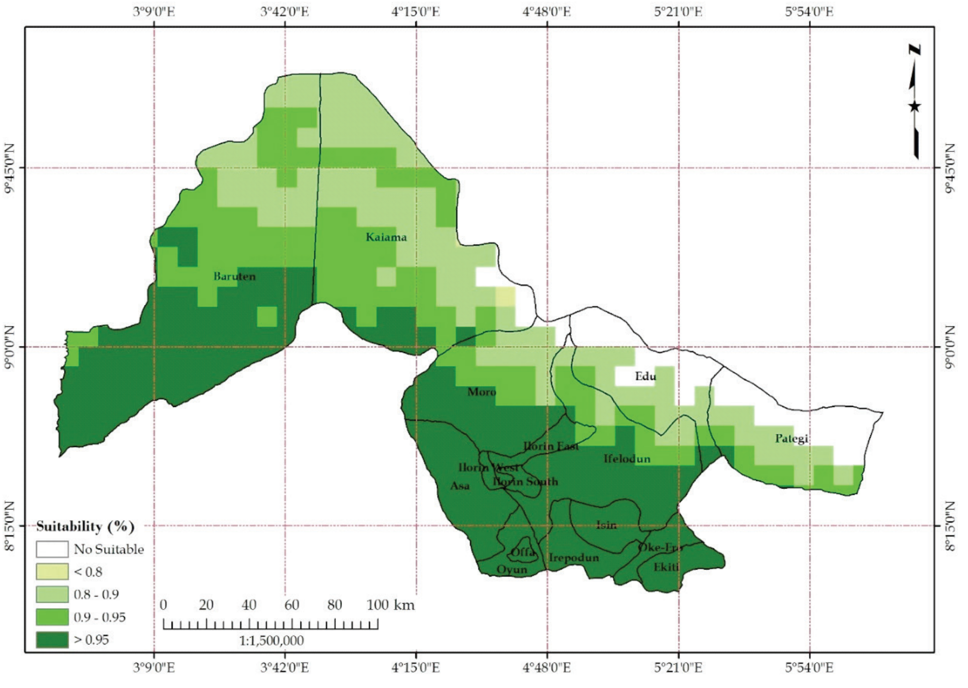

Fig. 19. Yam Suitability Map for 2050

CONCLUSION AND RECOMMENDATIONS

This study revealed the strong relationship between some climatic elements and agricultural crop yield in Kwara state, Nigeria. It has become obvious that climate has a significant influence on crop yield and change in the temperature, humidity and rainfall will affect crop yield. The effect will be very serious because the farming activities in the state depends largely on the vagaries of weather i.e. rain fed agriculture.

A projection of the climatic variation in the state revealed that climatic suitability level for predominant crops tuber (yam and cassava) and grain (maize and cowpea) in the state will reduce in the future because their production is dependent on rainfall. Consequently, their yield will continue to reduce unless necessary actions are taken against the challenges posed by climate. The study therefore, recommends sensitizing and educating the farmers about the trend in the influence of climate on their farming activities, adoption of new technologies to adapt to changes in climate and development of improved seedlings that has potentials to adapt to the changing climate.

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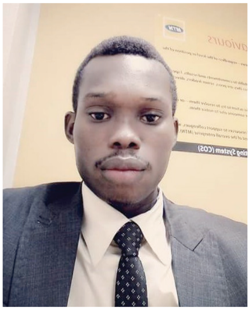

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"GREEN" DEVELOPMENT OF THE UGRA TERRITORY: OPTIONS AND OBSTACLES

ABSTRACT. Sharp differences in natural environment and resources and demographic and economic characteristics in Russia place special importance on analysis of regional models of transition to "green economy." Regional model of transition to"green economy" for the Khanty-Mansi Autonomous Okrug-Ugra is discussed. This region is situated in Siberia and is leading in hydrocarbons extraction (57% of the country's total). The existing nature management pattern is closely connected with poor modern ecological situation. System analysis of preconditions for the transition of the Khanty-Mansi Autonomous Okrug-Ugra to green economy is presented. It includes description of limiting and promoting natural and social-economic factors and consideration of the ecological situation. Economic, institutional, and nature management tools for regional transition to "green economy" and sustainable development are demonstrated. These tools reflect regional pattern of "green economy" movement, though common mechanisms play the leading role (e.g., energy efficiency, climatically neutral production, environmental accounting, etc.). Regional pattern includes specific measures for forests preservation, ethnic-culture tourism development, organic agriculture based on reindeer meet, wild berries and mushrooms production, etc.

KEY WORDS: sustainable development, green economy, Ugra, system analysis

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INTRODUCTION

Global economic crises along with increasing anthropogenic environmental impact, population growth, climatic change, etc., promoted the "green economy" development model to mitigate these negative processes. International community adopted several important documents fostering the transition to "green economy." Among them are the European program "20:20:20" directed at industry and power production "greening," the UNEP "Green Course," the "Rio+20" Declaration, etc. According to these documents, the main target of "green economy" is stabilization of economy development based on harmonization of "nature-population-economy" interrelations. Nowadays, positive achievements in promotion of green economy goals may be already found in post-industrial states (Germany, Scandinavian countries, etc.). The "green economy" concept for Russia is relatively new and this term is not used in official documents. Nevertheless, Russia's future development programs for the next 10-20 year period correspond to the "green economy" goals. It is obvious that mechanisms of transition to "green economy" will differ from state to state and even at a regional level in connection with environmental and socio-economic situation. Sharp differences in natural environment and resources, demographic and economic characteristics in Russia place special importance on analysis of regional models of transition to "green economy." Its urgency is demonstrated by several regions of Russia. Among them is the Khanty-Mansi Autonomous Okrug-Ugra which has launched this process by developing a special program. Integrated assessment of preconditions for further green development were included into this program.

MATERIALS AND METHODS

The Khanty-Mansi Autonomous Okrug (region)-Ugra is one of the leading Siberian regions in economic development based mainly on hydrocarbons extraction (57% from the country's total) (Fig.1).

Priority given to the industrial land management model since 1964 has caused negative environmental changes promoted by the present-day climatic change. In 2016, the total volume of extracted oil fell from 46% of the total production in Russia to 43.9%. Continuous deterioration of resource quality and economic factors are responsible for decrease of the current oil extraction levels.

The existing nature management pattern is closely connected with modern ecological situation. The following ecological problems are typical:

- environment pollution, including uncontrolled accumulation of solid waste as the most urgent environmental problem;

- ecosystem mechanical disturbances connected with hydrocarbon extraction development; and

- degradation of reindeer pastures leading to aborigine population existence problems.

Hydrocarbon extraction is associated with poor air quality in locations near oil wells. 93.6% of air-born pollutants are gasses (CO, NOx, SO2, formaldehyde, benzo[a]pyrene, etc.) and 6.4% are solid particles. The air-born pollutants load is 4.5 t/km2 [State Report…, 2015]. Pollution of surface and underground water systems is significant. Very acute problems are connected with accidents on pipe-lines and soils re-cultivation in heavily polluted areas. A separate ecological problem is industrial and communal wastes management. More than 100 landfills exist nowadays and more than half of them are uncontrolled [State Report…, 2015].

Fig.1. The Khanty-Mansi Autonomous Okrug.

There are several specific "northern" risks connected with environmental factors. These risks include cryological, exogenic geological, and hydro meteorological. Among them are thermokarst effects, solifluction, landslides and avalanches in mountains (Berezovsky district) and from steep river banks, mudflows, erosion, floods, etc.

We used system analysis for studies of preconditions of the Khanty-Mansi Okrug -Ugra transition to "green economy." It enabled processing various data: environmental, social, economic, etc., for determining their links to development of "green economy." Regional statistics, economic and environment reports, field data received during earlier studies, published data, etc., were used in our investigation.

RESULTS AND DISCUSSION

Ambitious plans for future development announced by the local administration are connected with the transition to the "green economy" model and the creation of "Clean Ugra" brand. UN experts mark five vital for "green economy" sectors: energy supply, transition to renewable energy sources, waste processing, organic agriculture, environment-friendly transport, and rational water resources use. Nowadays, Ugra's economic development is based on limited options of natural capital exploitation. Renewable energy sources, biological resources (timber, hunting and fishing etc.), and recreational resources are used inadequately but provide preconditions for economy diversification important for the transition to "green economy."

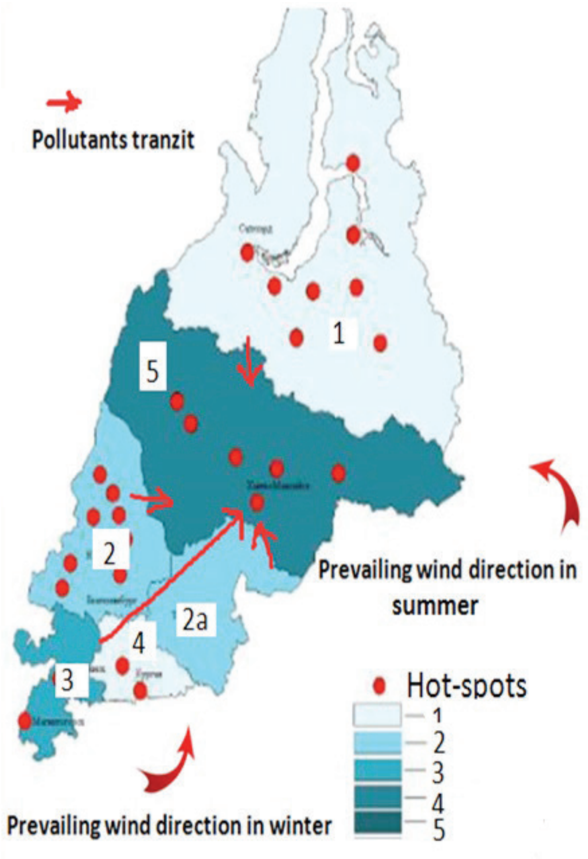

Fig. 2. Prevailing wind directions, pollutants transit routes, and environmental hot-spots.

1- Yamalo-Nenets Okrug, 2 Sverdlovskaya oblast, 2a- Tyumenskaya oblast, 3- Chelyabinskaya oblast, 4- Kurganskaya oblast, 5- Ugra.

Possibility of economy "greening" for the sake of sustainable development of any territory is provided by combination of different factors, both natural and social-economic. Climate change influences the global ecosystem processes thus involving social-economic changes. Globalization processes promote shift of "dirty" industries to developing countries, etc. The transition to "green economy" in Ugra meets various obstacles and options both limiting and promoting this process.

Limiting factors

Two blocks of limiting factors by origin exist in Ugra: natural and social-economic. Geographical position which influences

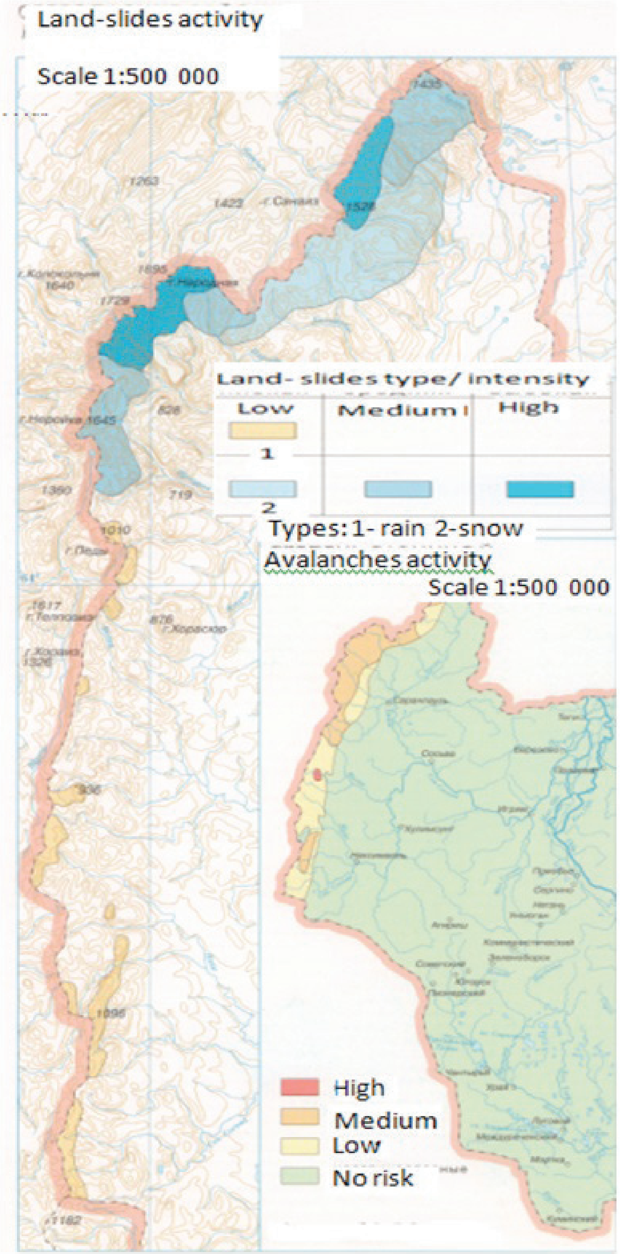

Fig.3. Land-slides and avalanches activity [Atlas…, 2004].

ecosystems stability in impact regions and ecological situation in general is the first to be regarded. Main natural limiting factors are connected with the Ugra geographical position promoting development of the following limiting factors: long cold winters demanding additional energy supply accompanied by negative ecological effects, unfavorable weather conditions, etc., slow biogeochemical turn-over(plant debris decomposition takes up to 20 years) and thus limited ecosystems self-purification capacity, promoting environmental pollutants accumulation in ecosystems, high percentage of bogged territories, relatively low biological productivity; long-range air pollutants transport from the Southern Ural and other neighbor industrial regions, water pollutants transported by transit river flow, etc. (Fig. 2). The list of environmental hot-spots compiled recently in the Ural Federative Okrug, where Ugra is located, includes about 50 sources of air-born and water pollutants [Report…, 2008].

Geomorphologic factors – land-slides and avalanches activities (Fig.3) and flooding of the Ob lowlands – must be also regarded as limiting factors. Patterns of atmosphere circulation produce high percentage of stills (20-30%) and heightened occurrence of air-born pollutants accumulation.

Nowadays, climate change represents an additional risk for "green economy" development. According to modern forecast data [Atlas…, 2004], two scenarios of temperature change (≈0.50C) exist for the region. According to V. Bysheva et al [2011], rise in annual average temperatures is forecasted for the middle of the 21st century. Decrease in relative air humidity will promote forest fire frequency. Permafrost thawing and solifluction will accelerate [Medvedkov, 2015]. Outbreaks of plant diseases, worsening sanitary-hygienic conditions due to permafrost thawing, and increase of areas of transmissible diseases such as malaria will accompany climatic warming. Positive changes are connected with higher biological productivity and turn-over, earlier and longer warm period, and more favorable living conditions. The opposite scenario (fall in temperature) development will promote increase of areas under permafrost in several parts of the region [Atlas…, 2004], continues pollutants accumulation in ecosystems, etc. But this scenario is less probable according to recent monitoring data.

Social-economic factors include history of industrial development, relatively recent introduction of ecological standards and inadequate system of pollution control during a long period of time. More than 50-year practice of hydrocarbons extraction started long before the development of important environmental protection standards, which became very actively used only by the end of the 20th century. Ecosystem losses is still occurring. The present-day role of Ugra as one of the state's leaders in economic development promotes further industrial nature management, though ecosystem losses reduce the regional GDP to a high extent: genuine domestic savings index is minus 45.69 [Bobylev et al., 2012]. Thus, Ugra permanently reduces its natural capital and increases rate of ecological degradation; however it promotes economic development of other regions (being an economic donor-region) providing "consumer surplus" free of charge for them as far as environment-forming ecosystem services are concerned.

Promoting factors

Promoting factors are connected with large territories with minor technogenic impact and high share of forested (taiga) territories – more than 50% of which form ecological buffer zones mitigating negative anthropogenic impact. The history of nature conservation activities started in 1929 when the first nature reserve Sos'vinsky was founded. Nowadays, there are 24 natural protected territories which make 5.2% of the total Ugra area. Ecosystem structure of licensed oil extraction territories includes 40% of forested lands and 48% of bogged territories which may serve as carbon sequesters thus providing an important ecosystem service (GHG reduction) as well as filters for polluted air and run-off. Ecological buffer zones of nature protected territories may be enlarged by territories with traditional nature management of Khanty, Mansi and Nenets, occupying over 33% of the

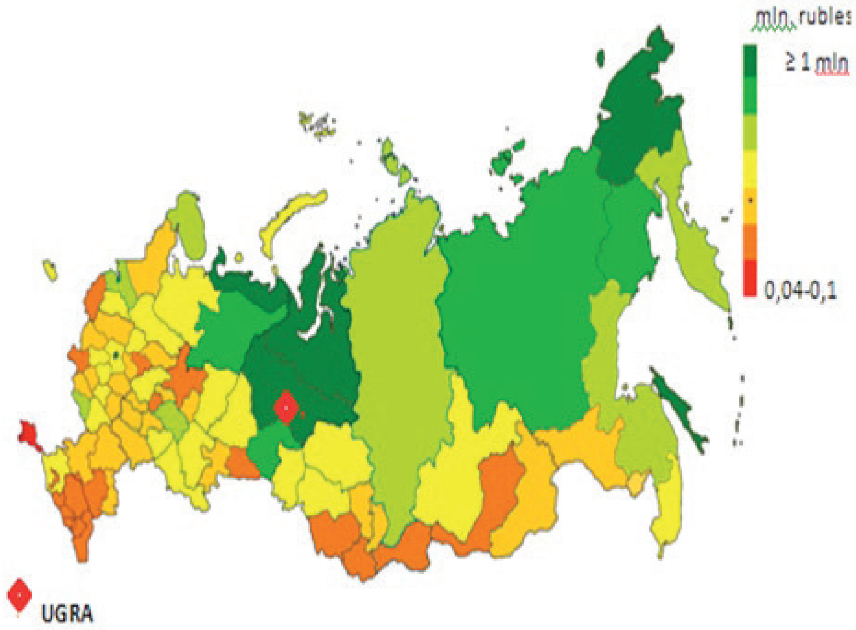

Fig.4 Gross regional product per capita (2014) – Ugra's position (based on: PlatonPskov [2014].

total area, but nearly 40% of them are in the licensed oil production sites, which demand special measures for their protection.

Favorable factors also include very high values of regional GDP compared to other regions of Russia (Fig. 4), more than 90% of economically active population, higher expenditures for technological innovations than in Russia, etc.

Options

Nowadays, many countries moving towards "green economy" take active measures to develop its brand based on sets of different tools corresponding to existing options. Analysis of preconditions for the Ugra's economy "greening" allowed outlining competitive advantages stipulating options for the "Clean Ugra" brand formation.

Renewable natural resources advantages. This region possesses high biological and recreational potential which may benefit economy diversification. Economic diversification based of renewable nature capital may provide favorable positions for Ugra in the on-going process of development of the world and regional ecosystem services markets. With the decreasing role of hydrocarbons fuel in future this, may bring good dividends to the Ugra sustainable socio-economic development.

The Ugra renewable energy sources potential is not very high, but still significant for exploitation. For example, wind energy potential is high in Beloyarsky and Berezovsky districts where the VAWT type of windmills

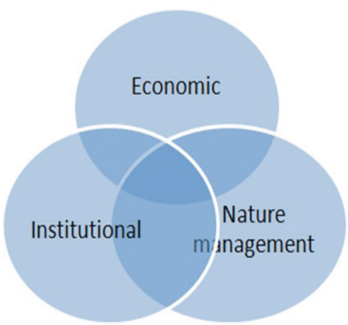

Fig.5 Options for the creation of the "Green Ugra" brand.

may de efficient. Solar energy resources assessed for optimal direction of solar batteries in the Kondinsky and the Surgutsky districts are comparable with that in the Rostov region in the steppe zone of Russia. High hydro energy potential is typical of small rivers in the Berezovsky district. Large amount of waste products in timber producing regions as well as agricultural waste products form a reliable source for biofuels production.

Socio-economic advantages. Having a relatively high level of economic development compared to other regions of Russia, Ugra has financial resources for investments in sustainable nature management, technological modernization, population ecological education, etc., for the sake of nature capital preserving and adequate exploitation.

Social competitive advantages are contributed to large investments in human capital development. Ugra is an attractive region for migration despite severe climate. A well educated population in professional and ecological spheres may be considered the leading social factor for sustainable development. Traditional ecological ethnic culture of indigenous population may help to find safe methods for modern ecosystems exploitation.

Fig. 5 shows the existing options for the creation of "Green Ugra" brand. They include economic, nature management, and institutional measures. Each option includes a set of tools directed at economic "greening" (Fig. 6, a-c)

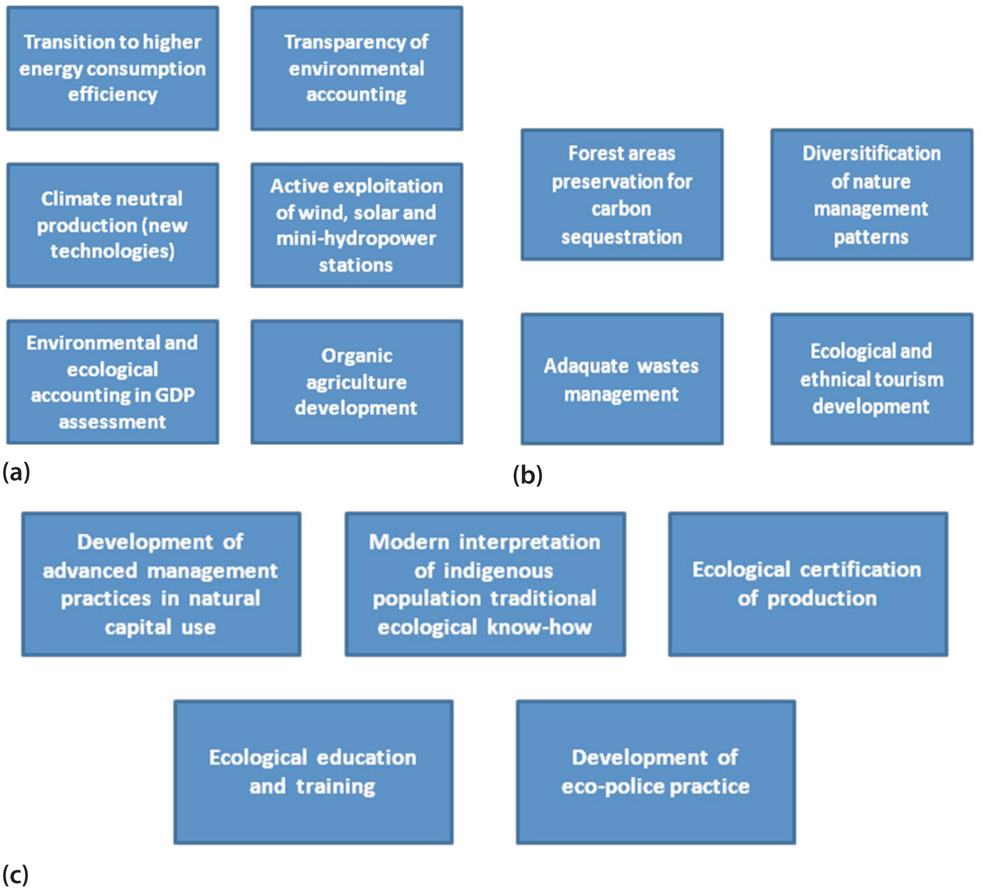

Fig. 6. a) Economic tools; b) Nature management tools; c) Institutional tools of economic "greening"

These tools reflect regional pattern of "green economy" movement, though common measures play the leading role (e.g., energy efficiency, climatically neutral production, ecological accounting, etc.). Regional pattern includes specific measures for forests preservation, ethnic-culture tourism development, organic agriculture based on reindeer meet, wild berries and mushrooms production, etc.

CONCLUSIONS

The administration of Ugra is now developing a special program directed at "Green Ugra" brand. Special attention is given to "green" technologies, proper industrial and communal wastes management, and nature conservation. Ugra has all chances to be the first resources exploitation region in Russia that actively promotes the transition to "green economy" and sustainable development despite economic and environmental obstacles.

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