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Changes of soil water regime types in the area adjacent to the Tomisławice open-cast lignite mine (central Poland)

Abstract: This work presents the results of a four-year study on the determination of the range of soil groundwater drainage caused by the operation of the Tomisławice lignite open-cast mine. The performed analyses covered the area of 9600 ha which included 24 villages. It was found that operation of Tomisławice open-cast mine caused noticeable changes of soil groundwater level in the areas adjacent to the excavation. It consequently resulted in considerable changes in soil water regimes types on grassland areas but it did not always lead to soil degradation processes. However, the deterioration of soils hydrological conditions may cause disappearance of certain hydrophilous grass species.

Keywords: groundwater level, degradation by drainage, depression cone

INTRODUCTION

Exploitation of various resources, in particular lignite, and employing for this purpose open-cast mining leads to significant hydrological and geomechanical transformations of the surface layer of the lithosphere (e.g. Rząsa et al. 1999, Uzarowicz et al. 2014, Gajewski et al. 2015). These changes are visible not only within boundaries of the open-cast mines, but often also in the areas adjacent to them (Glina et al. 2016). This is caused by the necessity to drain the open-cast mine before and during the lignite exploitation, and also by changes in the hydrological network of the territory (Rząsa et al. 1999, Mocek et al. 2002, Owczarzak et al. 2011, Grünewald 2001). The extent and intensity of such drainage was documented in the past in considerable detail and investigated thoroughly (Rząsa et. al 1999). Results of these interdisciplinary scientific investigations were usually presented as unpublished expertises for mine industry. In order to evaluate the scale of soil water regime changes caused by the activities of open-cast mining and to separate it from climate changes it is essential to recognise the initial state of the environment before the initiation of mining activities (Mocek et al. 1998, Rząsa et al. 2000, Owczarzak et al. 2008). Since 1970, many long-term laboratory investigations and field observations of drained soils – due to operation of open cast mine – have been conducted. They constitute a basis for forecasting the extent and direction of both natural and anthropogenic changes, including degradation of soil productivity due to drainage (Kasztelewicz and Zajączkowski 2010, Rząsa et al. 1999).

The main objective of the study was a synthetic analysis of a four-year investigation concerning the range of soil drainage in the vicinity of the Tomisławice open-cast mine (central Poland). Determination of boundaries of this range demarcated the area in which unfavourable changes may be expected to occur in farmland, especially in grassland soils. That in consequence will make possible to calculate appropriate compensations for farmers for losses in soil productivity.

MATERIALS AND METHODS

Study area

Tomisławice lignite open-cast mine, which started operations in 2010, is located in the north-eastern part of Wielkopolska (Fig. 1 and 2).

Soil science investigations were conducted in 24 villages constituting the area of 9600 ha, excluding the area intended for the open-cast pit (Fig. 1 and 2). The study area was situated in a region of distinct hypsometric differentiation ranging from 84.0 m a.s.l. (the Noteć River valley in the south) to 107.5 m a.s.l. (village of Zakręta – north-west of the investigation area). The entire study area is sliced by local depressions characterised by very variable water quantities depending on the season of the year.

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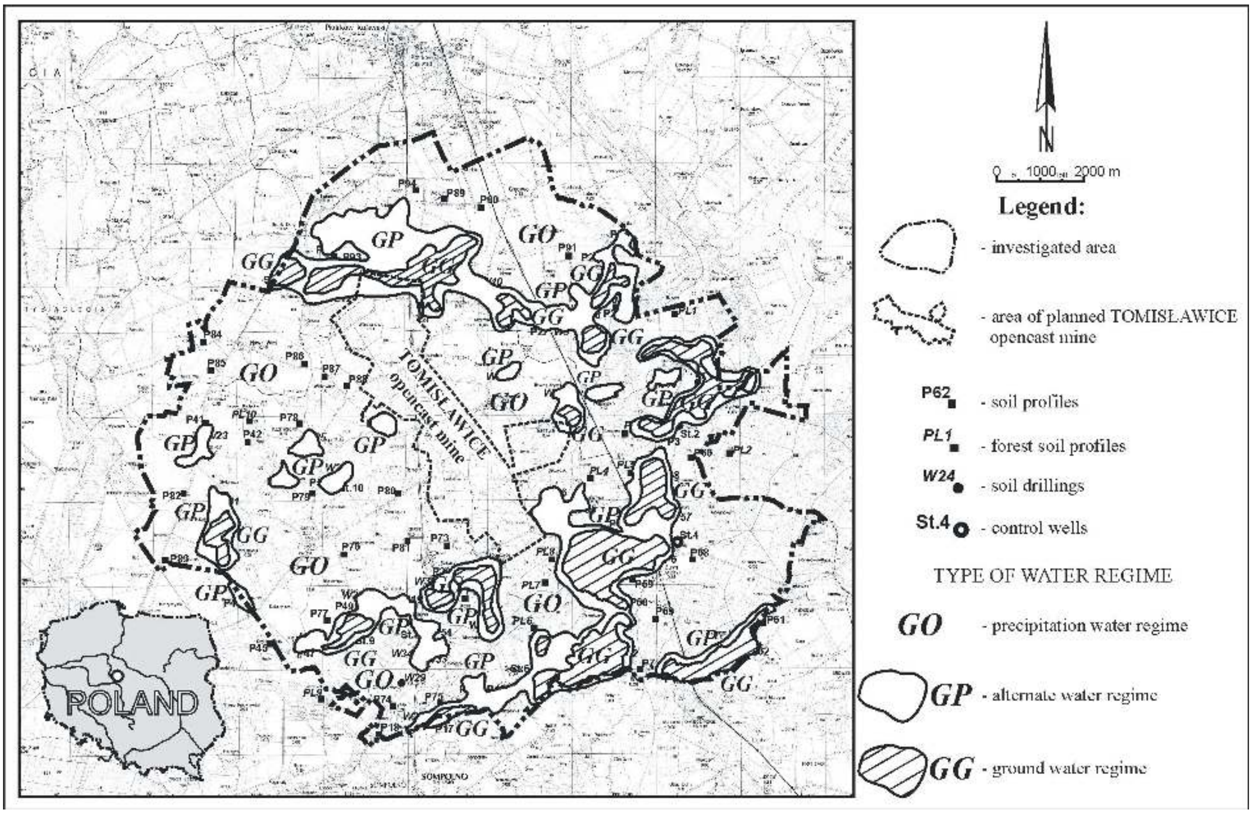

FIGURE 1. Map of soil water regime types of the study area prior to the opening the Tomisławice open-cast mine

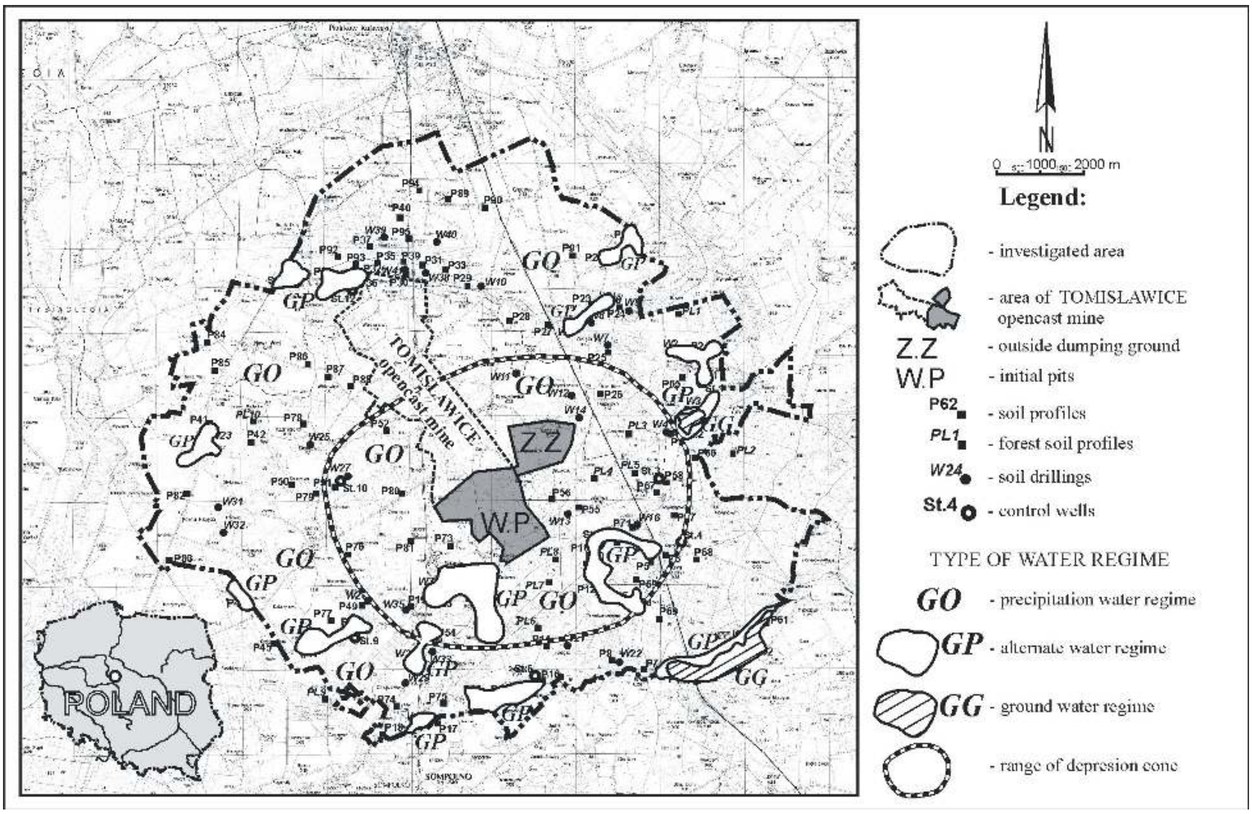

FIGURE 2. Map of soil water regime types of the study area following 2 years operation (2011–2012) of Tomisławice open-cast mine

Soil cover of the study area consists of many soil types among others, *Arenosols* (gleby rdzawe and arenosole), *Luvisols* (gleby płowe), *Cambisols* (gleby brunatne), *Phaeozems* (czarne ziemie), *Histosols* (gleby torfowe), *Histosols* and *Gleysols* (gleby murszowe and murszaste) (PSC 2011, IUSS WRB 2015). These soils exhibit considerably varied sensitivity to all kinds of the degradation of productivity due to drainage (Rząsa et al. 1999).

According to the data provided by PAK KWB KONIN S.A. within the boundaries of the analysed region, the following water-bearing horizons and levels can be distinguished: quaternary horizon, tertiary horizon, cretaceous horizon, overlayer level, carbonaceous level and cretaceous water-bearing level. From the point of view of maintenance of soil-ground water levels, the quaternary horizon is the most important. Waters of the quaternary horizon are supplied directly by atmospheric precipitation and, in the case of occurrence of deeper levels, indirectly by seepage or through hydrogeological windows. Water flows in this region are affected by the drainage character of the following water courses flowing in the neighbourhood of Tomisławice deposit: Maciczny Rów, Pichna, Noteć and Warta-Noteć Canal as well as of Gopło and Głuszyńskie lakes.

The depth of the Tomisławice open – cast mine is about 40.7 m. The maximum, theoretical area of depression cone (given by PAK KWB KONIN S.A.) corresponds roughly to the investigated area. The highest mean annual temperature (10.6°C) was recorded in 2008 while the lowest (8.4°C) in 2010. However, the mean annual air temperature in the year 2010 did not reflect the agro-meteorological conditions in late spring and summer, because of very low temperature in January (–7.0°C) and December (–5.8°C). The sum of precipitation in the year 2010 was very high (709 mm), whereas in the following year it was the lowest (389 mm). Based on the potential evaporation, it can be stated that in the study area the sum of annual precipitation do not cover the quantity of potential evaporation (Table 1). Similar conclusions was reported by Kędziora (2011), based on long term researches (14 years).

TABLE 1. Selected meteorological data for the study area in the years 2008–2012*

Year	Temperature [°C]		Percipitation [mm]		Potential evaporation [mm]
	annual	in growing season	annual	in growing season	
2008	10.6	16.9	426	174	831
2009	9.7	17.3	578	367	797
2010	8.4	16.6	799	504	721
2011	10.0	17.6	389	257	809
2012	9.1	16.2	503	287	805
Mean	9.6	16.9	539	318	743

*(data in table provided by PAK KWB KONIN S.A. and Nicolaus Copernicus University in Toruń).

Cartographic works and field study

Based on the collected cartographic documentation (topographic-altitude maps, land registry maps, soil-agricultural maps, hydrographical maps, hydrological sections etc.), an initial review of the area was performed. As a result of this assessment, areas potentially exposed to mine drainage dehydratation and to its negative consequences, were marked on topographical maps. Primarily, these included natural trough depressions neighbouring with former or current water courses, as well as land depressions without outflows. Field survey (initiated at the beginning of April 2008) was conducted in two time periods. The first in years 2008 –2009 (stage I – before the operation of the mine started) and the second in years 2011–2012 (stage II – mine in operation for 2 years). This two-stage approach of investigations (before and in the course of operation of the open-cast mine) turned out to be very effective in the case of areas affected by the drainage of Drzewce open-cast mine (Owczarzak et al. 2000, 2003). The scope of field studies was concentrated on soil morphology and measurements of the depth of groundwater level in soils. It was conducted in the fixed points (soil profiles, soil drillings – stage I and soil drillings, control wells – stage II) distributed in the study area. In years 2008–2009 (stage I), measurements of the groundwater level were conducted eight times (four times each year) in 146 points. The results of these measurements allowed to select location of 40 soil drillings and 12 control wells. The selected areas were considered as potentially exposed to mine drainage. The control wells were made from PVC pipes (ϕ 7.5 cm) protected by wooden boxes. Those points were used in permanent monitoring process (stage II – 2011–2012). During the monitoring period, measurements of soil groundwater levels were taken ten times (five times each year). Therefore, 1688 measurements of groundwater level were taken in the time periods 2008–2009 and 2011–2012.

RESULTS AND DISCUSSION

On the basis of the first stage of investigations it was found that soil groundwater level occurred at a wide range of depth. It extended from 0.20 m to over 3.0 m (below the soil surface). The registered seasonal changes in their levels fluctuated in a fairly wide interval ranging from several centimetres to the value of 1.80 m. Comparing mean depths from measurements in the same four months in years 2008 –2009 (i.e. before opening the mine), these differences were not big and fell most often within the interval of several centimetres. This indicated an exceptionally high stability of groundwater levels on the study area. This condition should be considered as natural influenced by many decades of processes resulting from both climatic conditions and agricultural use (Kędziora 2011, Glina et al. 2016).

The measuring of groundwater level in 2008–2009 allowed to distinguish three types of soil water regimes (Rząsa et al. 1999) in the study area as follows: precipitation water regime (GO) found on the major part of the study area (6912 ha, 72% of the study area), alternate water regime (GP) with a tendency towards precipitation regime which occurred on the area about 1699 ha (17.7%). The groundwater regime (GG) was found on a relatively small area – 989 ha (10.3% of the study area), mainly situated in the lowest altitudes (Table 2, Fig. 1). According to Rząsa et al. (1999) precipitation water regime occurs when the soil moisture and plant vegetation to a depth of 1.0 m (grassland) and 1.5 m (arable land) depend only on precipitation; alternate water regime means that soil moisture and plant vegetation depend both on precipitation and ground water level; the groundwater regime occurs when soil moisture and plant vegetation depend on groundwater level during the whole growing season. The mentioned authors regard that soil degradation by drainage can appear only in the cases of ground and partially alternate water regimes (alternate precipitation groundwater regime).

The definitive evaluation of the Tomisławice open-cast mine impact on the changes of soil water regime types was carried out in years 2011–2012 (stage II). Measurements of groundwater levels in this period were taken in 52 points selected from 146 points used during the period 2008–2009. They were situated in areas of ground and, partially, alternate soil water regime types in particular. In order to compare changes in groundwater levels in both periods, the authors proceed depth measurements of these waters in the same, fixed points. This allowed to determine changes of types of soil water regimes in those points. The following results of the performed analyses refer to 52 selected points (Table 3, Fig. 2). The following three regularities can be derived from these data:

– during the period 2011–2012, a decline in the number of points representing the ground type of water regime (GG) from 44.2 to 13.4% was determined in comparison with the period 2008–2009;
– during the period 2011–2012 the number of points representing the alternate type of water regime (GP) declined slightly (c.a. about 2%);
– the number of points representing the type of precipitation water regime (GO) increased dramatically from 7.7% in years 2008–2009 to 40.4% in the period 2011–2012.
– those changes were caused by climatic factors as well as by mine activity.
– current range of depression cone (Fig. 2.) indicates areas, which were influenced by mine activity. It was confirmed by very pronounced (even more then 4 meters) decrease of groundwater levels.

TABLE 2. Types of water regimes of the examined soils

Type of water regime: rain / ground-rain / ground	Investigated points	Approximate area influence by Tomisławice open-cast mine
1. Precipitation water regime – GO*	Profiles no.: 7, 11, 13, 15, 18–19, 24–25, 29, 41–47, 65–69, 71–96, PL-1-PL-10 Soil drilling: 29, 33, 36, 37, 38	6.912 ha, it is 72% of the area lack of any negative impac
2. Alternate water regime – GP* – ground/precipitation water regime – GPg* – precipitation/ground water regime – GPpo*	Profiles no.: 21, 22, 27, 35, 39, 40, 49–51, 55, 56 Soil drilling: 11, 21, 26, 39, 41 Profiles no.: 2–4, 20, 23, 26, 28, 36–38, 52, 54, 59 Soil drilling: 2, 5, 8, 9, 12, 13, 19, 23, 27, 28, 31, 34-36, 40	Total GPo + GPg – 1699 ha, it is 17.7% of the area at GPo – favourable land melioration effect, at GPg – in exceptional cases (e.g. long-term summer drought) – inhibition of meadow growth
3. Ground water regime – GG*	Profiles no.: 1, 5, 6, 8, 9, 10, 12, 14, 16, 17, 30-34, 48, 53, 57, 58, 60–64, 70 Soil drilling: 1, 3, 4, 6, 7, 14–18, 20, 22, 24, 25, 30, 32	993 989 ha, it is 10.3% of the area favourable land melioration effect, degradation of grasslands (cultivation necessary)**

* types of soil water regimes were describe in the text; ** degradation of bog plants (lack of economically valuable grasslands plants).

TABLE 3. Mean groundwater level and changes in soil water regime types in years 2008–2009 and 2011–2012

Groundwater table position	Depth interval (cm)	Years 2008–2009			Years 2011–2012			Soil water regime changes in the studied periods
		number of points	total area [%]	ground-water level [cm]	number of points	total area [%]	ground-water level [cm]	
Very shallow	0–50	1	1.9	40	1	1.9	39	Ground water regime – GP 44.2% →13.4%
Shallow	51–100	22	42.3	86	6	11.5	79	
Moderately deep	101–150	25	48.1	114	24	46.2	125	Alternatewater regime – GP 48.1% →46.2%
Deep	151–200	3	5.8	160	6	11.5	165	
Very deep	201–250	–	–	–	1	1.9	205	Precipitation water regime – GO 7.7% →40.4%
	<251	1	1.9	<250	14	26.9	<400	
TOTAL		52	100			52	100	

– in other investigated areas changes of groundwater levels were visible but lower (c.a. 0.4–0.6 m) and they were caused probably only by climatic factors.

Taking into consideration the above mentioned changes and a possible range of the depression cone of the Tomisławice open-cast mine (Fig. 2), areas of grasslands where compensations are supposed to be paid for the sward cultivation were marked on soil-agricultural maps in 1:5000 scale (not shown). The total area of these grasslands was 420 ha which constitutes only 4.38% of the entire area under investigations (Table 4). Dropping of groundwater levels did not deteriorate (in many cases) properties of the

TABLE 4. Grassland areas affected by Tomisławice open-cast mine drainage degradation at the end of 2012 which are expected to be paid compensation for the sward cultivation

No.	Village	*Change of soil water regimes types of grasslands	**Land capability units typeand subtype of grasslands	Grassland areas (ha)
1	Boguszyce	GG→ GP	2zM, 3zM	31.5
2	Bycz	GG→GP; GP→GO	2zM	1.6
3	Chlebowo	GG→GP	2zM, 2zEmt	45.8
4	Gaj	GP→GO	3zM	5.4
5	Galczyce	GG→GP→GO	2zM, 3zM, 3zEmt	16.2
6	Goczki	GG→GP; GP→GO	2zDz, 2zM, 3zTn, 3zEmt	57.9
7	Kazubek	GG→GP; GP→GO	3zM, 2zEmt, 3zEmt	6.5
8	Kryszkowice	GP→GO	2zM, 3zM	6.2
9	Krzymowo	GP→GO	–	no change
10	Łysek	GG→GP	2zM, 3zM	14.8
11	Ostrowo	no change	2zM	6.5
12	Palmowo	GP→GO	2zM	7.7
13	Pamiątka	GG→GP; GP→GO	3zDz, 3zM	12.3
14	Sadlno	no change	2zM, 3zM, 2zEmt, 3zEmt	4.9
15	Słomkowo	GP→GO	2zM, 3zM	16.1
16	Synogać	GG→GP; GP→GO	3zDz, 3zM	70.2
17	Teodorowo	GP→GO	3zDz	8.9
18	Tomisławice	GG→GP; GP→GO	–	no change
19	Władysławowo	GG i GP→GO	3zDz	5.7
20	Wyrobki	GG i GP→GO	3zDz	0.7
21	Zakręta	GG i GP→GO	–	no change
22	Zaryń	GG→GP; GP→ O	3zM, 3zEmt	48.2
23	Zielonka	GG→GP; GP→GO	3zDz, 3zM	38.6
24	Ziemięcin	no change	2zM	14.3
Total area of grasslands				420.0

Explanation: * Water regime types: GO – precipitation water regime, GP – ground/precipitation water regime, GG – ground water regime; **Land capability units of grasslands: 2z – medium, 3z – weak and very weak; **/ **Type and subtype of soil: Dz – Black earths, M – Mucky soils, Tn – Peat soils, Emt – Peat soils on alluvial subsoils.

soils' epipedons itself. It was corroborated by the fact that domination of muck soils among the soil cover of the study area was observed already in the past (Rząsa et. al. 1999). Surface horizons of those soils had been already affected by the processes of organic matter transformation in the case of moorsh-forming process. It was a result of a natural trend to a decrease of groundwater level associated with the intensification of agricultural production. This is confirmed by descriptions and symbols of individual soil contours found on soil-agricultural maps prepared in 1960s and 1970s. Initial water regime of majority of investigated soils changed into an alternate water regime and, sporadically, even into precipitation water regime. The natural and agricultural drainage degradation may have only been slightly intensified by the operation of the open-cast mining.

CONCLUSIONS

1. Two years of Tomisławice open-cast mine operation resulted in noticeable changes in soil groundwater levels, as well as in their types of soil water regime.
2. The observed changes were noticed mainly in muck soils and black earths, on the relative small area.
3. The drop of the groundwater level did not and probably will not contribute to soil degradation because in mentioned soils such processes were found to occur already in the past due to natural processes.
4. The changes in groundwater level may cause greater losses of precipitation water infiltrating into deeply situated groundwater table. It reduces possibilities of capillary rise. This, in turn, may exert a negative influence on the vegetation of plant cover of grasslands, especially during periods of low atmospheric precipitation or long-term drought.

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Zmiany gospodarki wodnej gleb w rejonie przylegającym do odkrywkowej kopalni węgla brunatnego „Tomisławice" (centralna Polska)

Streszczenie: Celem pracy była analiza 4-letnich badań dotyczących określenia zasięgu odwodnienia gleb, spowodowanego działalnością odkrywki węgla brunatnego „Tomisławice". Obszar badań obejmował 24 wsie zajmujące powierzchnię 9600 ha. Obniżenie zwierciadła wód glebowo-gruntowych zaobserwowano na relatywnie niewielkim obszarze, w najbliższym sąsiedztwie wyrobiska, głównie na użytkach zielonych. Spowodowało ono zmiany w typach gospodarki wodnej gleb. Gleby semi- i hydrogeniczne rejonu badań charakteryzują się silnym, naturalnym (klimatycznym) ewolucyjnym, jak również agronomicznym przeobrażeniem. Kopalniane obniżenie poziomu zwierciadła wód glebowo-gruntowych nie spowodowało zatem ich dalszej degradacji. Jednak pogorszenie warunków hydrologicznych gleb może spowodować zanik niektórych hydrolubnych gatunków traw.

Słowa kluczowe: zwierciadło wody gruntowej, degradacja odwodnieniowa, lej depresji