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4. QUALITY OF GROUNDWATERS IN THE AREA OF THE ŁÓDŹ BASIN

4.1. Introduction

Geography as a science provides the image of spatial changes in environmental phenomena, and specifies their character and causes for such variability. The civilisation progress triggers the necessity to consider the human contribution to the character of natural phenomena and their variability in time and space. The scale of transformations documenting such participation is already extensive enough to provide the basis for distinguishing a new, artificial component of the environment in addition to the natural ones, namely anthroposphere. It fills the niche resulting from the transformation of all environmental components in places inhabited and influenced by man. From the point of view of the perspectives of the civilisation development, it seems very important to determine general processes occurring at the boundary of this artificial component of the environment with its remaining, natural elements: lithosphere with anthroposphere, hydrosphere with anthroposphere, biosphere with anthroposphere etc. The processes occurring between the

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natural environmental components have shaped the image of the Earth from the beginning of time. They have become the foundation of its diversity and abundance. The interactions of the environment with the anthroposphere are something new, in terms of their quantity, intensity, and quality. The effects of these interactions are observed at varied temporal scales. Some of them are already well known, and we are learning to forecast them. Others are still far beyond our horizons, and will only be observed by future generations. Such effects are increasingly appearing to become an obstacle, a barrier for our civilisation development. They are also becoming another challenge to man.

The history of Łódź seems to be a good example. As a great industrial city, it developed far from large rivers, i.e. in the conditions of seemingly limited access to water resources. Due to the intensity of its development, the city was called "the fungus city". Like fungi, it needed vast amounts of water. The local resources were rapidly exhausted, although the necessity of using them at the first stage of the city's development affected its urban arrangement. Larger resources of surface waters in the Pilica and Warta River valleys were too distant as for the contemporary economic market. Following the example of other urban centres developing intensively at the time in Europe, and dealing with the problem of ensuring access to clean water, attention was paid to groundwaters. For a number of years, they became the basis of existence of the city of Łódź, and permitted its further robust development. The city's economic history saw moments of crisis, when local needs reached the maximum level of available resources and exceeded it. Interestingly, such a situation has always had a qualitative character, but was also related to the issue of relevant quality of water used for specific production processes. The determination in overcoming the environmental obstacles translated into the state of knowledge on the environment surrounding this particular urban centre. Reaching for deeper and deeper deposits of groundwaters in search for new available local resources, the underground, and following the city's spatial development and construction of new factories in former suburbs, also the spatial variability of geological conditions was documented. In 1930, the first successful attempt of synthesis of the collected knowledge was undertaken. Professor J. Samsonowicz used the term "Łódź basin" (following Kolago 1957). Such tectonic structure underlying younger Cainozoic formations accounted for the very good conditions of accumulation in the Mesozoic rocks of modern meteorological waters, and therefore the development of a very abundant reservoir of freshwaters. The said reservoir turned out to be the deepest complex of freshwater geological structures in Poland.

The concentration of industry and human population, and the accompanying local intensification of agriculture, affected the groundwater environment. In addition to the progressing qualitative degradation, also the scale of anthropogenic pollution increased, along with the risk of activation of new type of threats confined deep below the city's surface, namely geogenic factors (Bojarski and Sokołowski, 1994). The decline of the Łódź Industrial Centre resulted in a drastic decrease in demand for water (Table 4.1). Due to this, the degraded resources, particularly those of waters in the Cretaceous formations, are successively reconstructed. Due to the very long time of their exchange, however (Ziułkiewicz 2003a), many pollutants are still evidently present. They constitute the evidence of the unconcern of former authorities of Łódź for the future generations.

Table 4.1. Consumption of groundwaters in the Łódź industrial district by the trade, cf. 1960 and 1999 years

City	Consumption [m^3/d]	
	1969*	1999**
Aleksandrów Łódzki	663	334
Konstantynów Łódzki	233	176
Łódź	62 722	17 882
Pabianice	15 090	7 753
Zgierz	28 615	4 618

Source: * Skłodowski (1971); ** WIOŚ Łódź (2000).

The following work presents works carried out in the Laboratory of Geology of the University of Łódź in the scope of the identification of the quality of groundwaters and potential causes of their pollution in the area of the Łódź basin. It constitutes a review of studies from the period 1993–2013.

4.2. The Łódź basin

4.2.1. Structural unit

In terms of its structure, the Łódź basin is an element of the Mogilno-Łódź synclinorium, constituting a component of a complex of large Mesozoic units occurring throughout Poland except for the Carpathians and Upper Silesia. The structures developed from Permian and Mesozoic rocks in place of an extensive central Polish basin. The water body developed after the variscan orogeny in the Lower Permian, and the Mesozoic units fully developed at the end of the Cretaceous, during the laramian phase (Stupnicka 1989). They are large-radius units with very low amplitudes in relation to their stretch. They locally show a considerable degree of concentration of tectonic disturbances, accompanied by phenomena caused by halokinesis (Figure 4.1). In the area of the Łódź basin, one of such faults was determined, recorded in a series of anticlines, including the Lutomierska and Pabianice anticlines. Their development was largely influenced by advanced halokinetic processes. They did not cease in the Mesozoic, but continued with various intensity in the Neogene. They probably continue until the present day. An example of intensive saline tectonics in the area of Łódź is the Rogoźno salt dome (Figure 4.1). The area of the Łódź basin contains a number of primary tectonic lines permitting the division of the study area into basic structural units (Figure 4.1). The fault zone Ozorków–Lutomiersk–Pabianice distinguishes the north-eastern fragment of the Łódź basin, developing a small synclinic formation with the axis running more or less along the line Ozorków–Aleksandrów–Konstantynów. It is much shallower than the main part of the Mogilno-Łódź basin (Ziułkiewicz, 2003a).

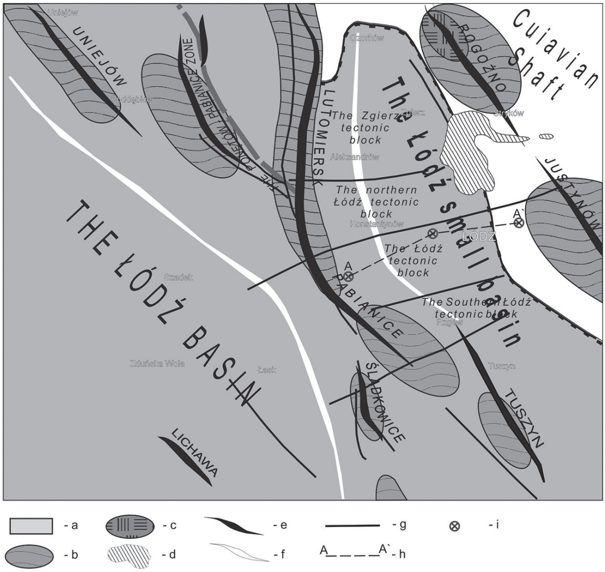

Figure 4.1. Tectonic map of the Łódź cretaceous basin in its north-eastern part after M. Ziułkiewicz (2003a)

a – the area of the Łódź cretaceous basin and its eastern border (Stupnicka 1989), b – salt pillows (Dadlez 1998), c – salt diapires piercing Mesosoic sediments (Dadlez 1998), d – range of glacitectonic disturbances (Piwocki 1975), e – anticlinal zone (Marek 1977), f – synclinal axis, g – main faults (Marek 1977, Mrozek 1975, Kasjański et al. 1972), h – lines of geological cross section – Figure 4.2, i – deep boreholes used for the construction of geological cross-section

Source: based on above-mentioned authors

F. Kasjański et al. (1972) propose the term "Łódź basin" describing the area from the Ozorków bay to the north to the Tomaszów-Opoczno bay to the south. In order to distinguish this part from the primary synclinorium, the term "small Łódź basin" will be used further in the work. Its western boundary is the primary fault reaching the Tuszyn anticline (Figure 4.1). The eastern boundary is marked by the Sub-Cainozoic outcrop of the thill of Lower Cretaceous deposits. A whole series of faults occur, perpendicular to the primary fault line Ozorków–Lutomiersk–Pabianice, running from north-west to south-east. They divide the small Łódź basin into four tectonic blocks, declining in a step-like manner from north to south, i.e. from Zgierz through Łódź towards Rzgów. These are: the Zgierz block, north-Łódź block, Łódź block, and south-Łódź block (Figure 4.1).

4.2.2. Hydrogeological conditions

The modern image of the geological structure and hydrogenic conditions of the Łódź basin results from mutual relations between the lithofacial development of rock formations and the degree of their tectonic involvement. The possibilities of exploitation of a given hydrogeological environment are always eventually determined by the mutual relationship between permeable and non-permeable formations. The Łódź basin constitutes an abundant reservoir of groundwaters extracted from a number of aquifers, from the Jurassic one through the Cretaceous and Neogene, to the Quaternary aquifer. In the area's geological past, a number of processes occurred resulting in the improvement of the conditions of development of groundwater deposits in rock masses. These include: decalcification of carbonate minerals, halokinesis, glacitectonics, and periglacial processes.

The primary role in the supply of water to cities in the area of the Łódź basin is played by porous and fissure-porous waters occurring in Lower Cretaceous sandstones and sands, as well as fissure and fissure-karst waters circulating in the Upper Cretaceous opokas, limestones, and margles. Due to the character of the sedimentation basin of the Łódź basin, the uppermost layer of the Lower Cretaceous sandy aquifer occurs at various depths, from 10 m on the outcrops to 2600 m on the primary synclinic axis (Figure 4.1). Outcrops occur along the edge of the Kujavian rampart and Fore-Sudetic Monocline. The aquifer is fed in the outcrop area with water from the overlying Cainozoic deposits, where the hydrostatic pressure in the Cainozoic aquifer reaches 10 m water gauge in relation to the Lower Cretaceous aquifer. From the outcrop zone towards the axis of the syncline, Lower Cretaceous aquifers collapse in the area of the Łódź agglomeration (Figure 4.2), and along with the penetration of the basin fraction by water, the hydrostatic pressure increases. According to M. Bierkowska et al. (1990), it can reach 1000 kPa, whereas in the outcrop area, it does not exceed 100 kPa. The water runoff partially follows the decline of rock layers towards the west and north-west. In the easternmost fragment of the Zgierz bay of the small Łódź basin, water flows in the north-western direction. There, in the drainage zone, it mixes with the Cainozoic waters, developing a zone of waters with substantially increased temperature, extracted through wells in Ozorków (Kolago 1957). The regional drainage base at the scale of a hydrogeological unit is composed of deep zones of the Łódź and Mogilno basins. Good filtering properties (Table 4.2), high hydraulic declines in the outcrop area, and the homogeneity of the aquifer (no disturbances in the hydroisohypes image) present the Lower Cretaceous aquifer as the best supplied among all of the aquifers studied so far within the Łódź basin (Kasjański et al. 1972). At the average filtration coefficient of $2.78 \cdot 10^{-5}$ m/s, water discharge of 45 m/year was determined.

Table 4.2. Characteristics of the Łódź basin main groundwaters horizones and theirs kainozoic sediments overlayer

Groundwater horizones	Lithology	Value of the Darcy coefficient k [m/s]
1	2	3
Quaternary	Fine-grained sands, medium-grained sands, gravel-sands aggregate with interbedding the loams, silts and snady clays	$2.4 \cdot 10^{-5} – 8.1 \cdot 10^{-4}$
Neogen	Fine-grained sands	$2.4 \cdot 10^{-5} – 8.0 \cdot 10^{-5}$

Table 4.2. (cont.)

1	2	3
Upper Cretaceous	Grazes aggregate with marle and sands, limestones and marly limestones	$1.3 \cdot 10^{-6} – 2.0 \cdot 10^{-3}$
Lower Cretaceous	Sands and weak compact medium- and coarse-grained sandstones	$7.7 \cdot 10^{-5} – 5.8 \cdot 10^{-4}$

Source: own study based on the M. Bierkowska at el. (1990) and F. Kasjański at el. (1972).

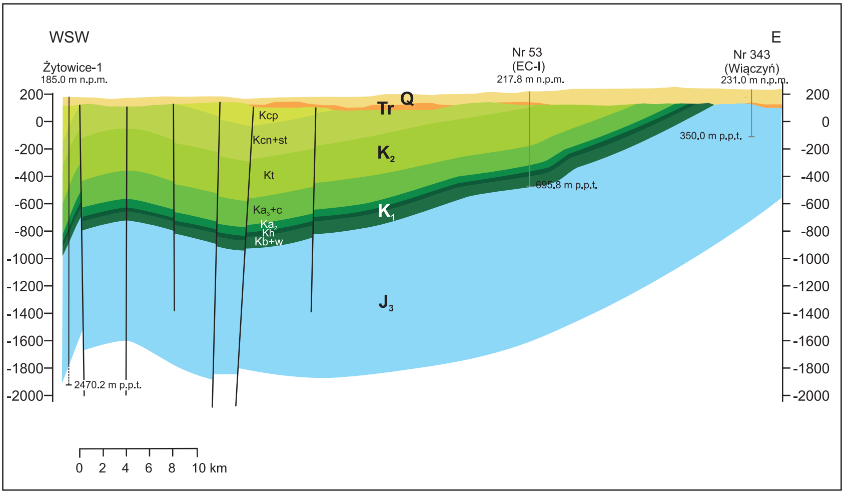

Figure 4.2. Schematic cross-section central part of the Łódź cretaceous small basin

Source: based on M. Ziułkiewicz (2003a)

Upper Cretaceous aquifers are located at a depth of 40–140 m. They developed a confined-unconfined aquifer. Water table is observed among others in Łódź, Zgierz, and within the diminishing depression cones. In a large portion of the area of the Łódź basin, confined waters occur with the hydrostatic pressure reaching 1200 kPa (Bierkowska et al. 1990). The alimentation of the Upper Cretaceous aquifers primarily occurs through drainage of the overlying Cainozoic aquifers. Due to the extensive distribution of Pre-Quaternary loams and Quaternary clays, however, water supply primarily occurs by very slow seepage. This is confirmed by the findings by M. Ziułkiewicz (2003a, b), suggesting the age of waters from the Upper Cretaceous aquifers amounting to 8000 years. Cainozoic sandy formations have no significant effect on the alimentation of the Upper Cretaceous aquifers due to their limited spatial range (lenticular aquifers) and no hydraulic contact with the more abundant intermorainic Quaternary aquifer (Kasjański et al. 1972). Weak alimentation of the Upper Cretaceous aquifer in the eastern fraction of the small Łódź basin, in the area of its Sub-Cainozoic outcrops, was confirmed by the observation of no visible decrease in the water level in the main Cainozoic aquifer along with the deepening of the Łódź depression cone, even when the difference in hydrostatic pressures between the two aquifers exceeded 100 m water gauge in a number of places (Kasjański et al. 1972). Alimentation of the Upper Cretaceous aquifers also occurs in the zone of tectonic faults, e.g. in the anticlinic zone Ozorków–Lutomiersk–Pabianice, constituting the western boundary of the area of the small Łódź basin. The Upper Cretaceous aquifer has two clearly developed alimentation areas with the water table ordinates exceeding 205 m a.s.l.: the first one is the area of Tuszyn, and the other – an area in the NE part of Łódź, in the Łagiewnicki Forest. Apart from the depression cones, the water runoff from the mentioned water table elevations occurs towards the local drainage bases in larger river valleys (Warta, Grabia, Ner and Bzura). The regional drainage base, already outside the boundaries of the area discussed, is the Warsaw-Berlin streamway along its course from Koło to Dąbie (Bierkowska et al. 1990). The Upper Cretaceous aquifer is of a fissure-karst character, whereas the water bearing is largely determined by the lithological character of the weathering rocks. Margle and loamy margle saprolite is non-water bearing, and the cracks and fissures are filled with loose residual material. Weathering opokas were subject to decalcination and strong cracking, not leaving any loose residuum. Limestones, having local water bearing significance, depending on the degree of enrichment in siliceous minerals, have variable characteristics of collector properties (Table 4.1). An important feature of the uppermost parts of the Upper Cretaceous formations is their high porosity, frequently reaching up to 60%. Due to the variability of hydraulic properties in the vertical profile, combined with the block structure of the Łódź basin, fragments of the Upper Cretaceous aquifer with similar collector properties are located in various regions – tectonic blocks, at various depths. Therefore, they have no mutual contact, resulting in worsening the conditions of groundwater flow along the largest regional gradients.

In the area of the Łódź basin, the Neogene groundwater table is not continuous. The alimentation of the Neogene aquifers occurs through seepage of water from the overlying Quaternary formations, particularly in the zone of reduced thickness of clays and loams, or locally through discharges in hydrogeological windows (Bierkowska et al. 1990), also in zones of glacitectonic disturbances. The drainage base is composed of the underlying Upper Cretaceous formations and valley systems of larger rivers in the area – Ner and Bzura rivers. Water primarily occurs in fine sand interlayers in loams with low thickness of several tens of centimetres. In the southern part of Łódź, where sands are coarse, and thickness values reach up to 10 m, larger Neogene sandy series in the eastern part of Łódź are generally correlated with Quaternary deposits, and considered as a single aquifer.

Within the Quaternary formations covering the area of the Łódź basin, several aquifers occur with varied range and degree of hydrogenealogical connection with deeper aquifers. The intermorainic aquifer, confined by morainic clays of the San, Oder, and Warta River glaciations, is of the highest significance. This aquifer does not constitute a compact and coherent sediment series. It is frequently interlayered with weakly permeable materials. This results in the distinguishing of several aquifers. It occurs in a wide range of depths, from several to 80 m (Maksymiuk 1979, Bierkowska et al. 1990), and sometimes even deeper. Areas of water table development are located in the eastern part of the agglomeration, where the thickness of the sandy series reaches the highest values of up to 100 m. Towards the west and south, the thickness of sandy series decreases, and the contribution of clays increases, with simultaneous reduction of Quaternary formations. The alimentation of the intermorainic aquifer occurs through the seepage of precipitation waters through the layers of the overlying formations, including clays. Fissures filled with sands and gravels, determined in the clays of the Warta River glaciation (Maksymiuk 1979), are places of intensive water discharge. The aquifer is drained by rivers and streams of various sizes: Moszczenica, Sokołówka, Dobrzynka, and Ner. Along with the Quaternary submorainic aquifer, it is intensively drained in the zones of outcrops of Lower Cretaceous formations. It is estimated that the runoff of Quaternary waters down the Lower Cretaceous formations slightly exceeds 23 thous. m^3/d (Kasjański et al. 1972). Water runoff from the alimentation zones in the eastern part of the Łódź agglomeration occurs iu the northern direction, towards the Bzura River valley near Ozorkowo, to the west, towards the Ner River valley, and to the south, towards the Wolbórka River valley.

A. Kleczkowski (1966), the author of the first Polish regionalisation of underground freshwaters, included the area of Łódź to the region of the Cretaceous Miechowo and Mogilno-Łódź basins (VIII). He also pointed to the area of Łódź as a region of the deepest occurrence of freshwaters in Poland (up to 1000 m). The specificity of the Łódź region, providing the basis for its distinguishing as a separate hydrogeological unit, is determined by the following: a high depth range of the freshwater zone, the geostructural character of the geological unit – sedimentation basin, the hydrogeological character of the structure – artesian reservoir, the abundance of primary aquifers and their function in the water management system of the Łódź agglomeration – Cretaceous and Quaternary aquifers, intensive acquisition of groundwaters for the purposes of the industry and municipal services, and the related very good state of hydrogeological knowledge obtained owing to a high number of wells located within a relatively small area. The hydrogeological regionalisation of Poland includes the Łódź area to the southern, Mesozoic province (B) in the Łódź-Nida macroregion (B_2). Two regions were distinguished within its boundaries: the Łódź basin (XX) and the Nida basin (XXI). The Łódź basin region was divided into four sub-regions: northern (XXa), central (XXb), Łódź agglomeration (XXc), and Bełchatów (XXd). The Łódź agglomeration region corresponds to the small Łódź basin in this division.

The Łódź basin (XX) has an area of approximately 10 thous. km^2. The eastern and western boundaries are determined by the range of Cretaceous formations, neighbouring to the Jurassic formations of the central Polish anticlinorium and Fore-Sudetan monocline. To the south-east, the Łódź basin reaches Sub-Cainozoic Jurassic outcrops of the Radom elevation (Kodrąbia bar), neighbouring with the Miechów basin. The north-western boundary with the Mogilno basin is of an arbitrary character. The length of the Łódź basin along the NW-SE axis amounts to 170 km, and the maximum width reaches 75 km (Kolago and Płochniewski 1991).

4.2.3. The Łódź basin groundwater resources

The dynamically growing needs of the industry of Łódź have never been confronted with the water abundance of the rock environment. This forced intensive water-related investment activities as ad hoc solutions. As a result of such a situation, still at the end of the 1950s, the water management of Łódź was recognised as chaotic, or even anarchic. The first works in the scope of the determination and documentation of regional resources of the Łódź basin were carried out in 1960. The total determined part of groundwater resources for Łódź of 154 thous. m^3/d (Table 4.3) was accepted by the state geological authorities in 1961, and constituted the basis for their management in the city until 1983 (Diehl 1997).

Table 4.3. Comparison of until now confirm and assess the admissible volume of extracted groundwater for the Łódź zone

Year	Study	Total resources	Resources of useful aquifer [th. m³/d]		
		[th. m³/d]	Caino-zoic	Upper Creta-ceous	Lower Creta-ceous
1960	Geological and Engineenering Company, Cracow (Przedsiębiorstwo Geologiczno-Inżynierskie)	154.0	71.8	26.2	56.0
1962	Municipal Office of Building Projects in Łódź (Biuro Projektów Budownictwa Komunalnego)	181.0	57.0	68.0	56.0
1971	Geological Institute, Warsaw (Instytut Geologiczny)	157.6	51.0	40.3	66.3
1972	Hydrogeological Company, Łódź (Przedsiębiorstwo Hydrogeologiczne)	159.4	63.5	38.3	57.6
1983	POLGEOL, Warsaw	132.9	50.1	29.0	53.8
1961–1972	Office of the Łódź City (Urząd Miasta) – the sum of individual admissible volume of extracted groundwater	284.0	134.0	84.0	66.0

Note: the mark out parts of table concern the confirm volumes of groundwater supply, remain parts concern the assess groundwater supply.

Source: J. Diehl et al. (1973) and J. Diehl (1997).

The comparison of the volume of resources determined for particular usable aquifers (Table 4.3) suggests that the Upper Cretaceous aquifer was the most overexploited one. Depending on the value adopted for resources, it varies from 320% to 120%. The value for the Cainozoic aquifer was lower, from 270% to 53%. Only the exploitation of the Lower Cretaceous aquifer did not exceed the volume of regional resources, probably due to the low number of intake stations (20). For comparison, by 1972, a total of 191 Upper Cretaceous wells with a depth from 100 m to 350 m were established in Łódź. 118 of them were located in the city centre (Diehl et al. 1973).

The groundwater resources of the large Łódź basin, accumulated in the so-called Primary Usable Aquifers and converted into resource area units, make it one of the most abundant hydrogeological regions in Poland. In terms of the volume of single unit exploitation resources, specified by E. Wiencław and J. Mitręga (1985) as 190 $m^3 \cdot d^{-1} \cdot km^{-2}$, the region takes the third position, following the Lubusz region (231 $m^3 \cdot d^{-1} \cdot km^{-2}$) and the Toruń-Eberswald streamway (408 $m^3 \cdot d^{-1} \cdot km^{-2}$), and ahead of the region of the Mesozoic cover of the Świętokrzyskie Mountains.

4.2.4. Hydrochemical conditions

The waters of the Upper Cretaceous aquifer of the Łódź basin represent the hydrochemical type HCO_3-Ca with derivatives: HCO_3-Ca-Mg and more seldom HCO_3-Ca-Na. An increase in the content of sodium in the waters is accompanied by an increase in their mineralisation. The second frequently occurring type of waters is HCO_3-SO_4-Ca. In 1913, the Odessa Central Laboratory conducted a number of analyses of water sampled in Łódź from Upper Cretaceous formations. They were determined to have a hardness of 9.8–19.8^{o}n, concentration of chlorides of 7–14 mg/l, mean concentration of sulphates of 37.5 mg/l, and dry residue of 280–290 mg/l. These values are very similar to those obtained in much later studies from the years 1952–1964 and 1966–1968. In the 1960s, also no changes in the water chemism were observed, although it was a period of a substantial decrease in the water level as a result of use of the resources by the industry of Łódź (Macher 1966, Skłodowski 1971).

The waters of the Lower Cretaceous aquifer primarily represent the hydrochemical type HCO_3-Ca-Na, and more seldom HCO_3-Ca-Mg. Type HCO_3-SO_4-Ca was recorded in several cases. The oldest information on the waters of this aquifer used for the purposes of the former factory of Izaak Poznański comes from the paper by Lindley from 1900 (Kasjański et al. 1972). The water was distinguished by dry residue of 170–210 mg/l, concentration of chlorides of 2.4–2,8 mg/l, and that of iron of 2.2–8.0 mg/l. The comparison with later results of the analyses (1952–1958 and 1967–1968) showed no trend of increase in mineralisation, and no significant changes in concentrations of chlorides and total iron.

An environmental curiosity of the Cretaceous aquifer of the Łódź basin is the inversion of water mineralisation. Waters from the shallower Upper Cretaceous formations have mineralisation higher than those from Lower Cretaceous formations (Kolago 1957, Kasjański et al. 1972, Bierkowska et al. 1990, Ziułkiewicz 2003b). The dry residue of the "Upper Cretaceous" waters varies from 260 to 340 mg/l, and that of the "Lower Cretaceous" waters – from 150 to 220 mg/l. It is explained by the rate of water discharge and lithological character of the aquifer (Kasjański et al. 1972, Bierkowska et al. 1990). Younger studies show that the primary cause is a substantial disproportion of the age of waters of both of the Cretaceous aquifers (Ziułkiewicz 2003a, b).

A total of several tens of hydrochemical types were determined in the waters of the Cainozoic cover of the Łódź basin. They are dominated by triion (mostly HCO_3-SO_4-Ca), quadruple ion (HCO_3-SO_4-Ca-Na), and double ion waters (HCO_3-Ca). Results of long-term studies show a considerable transformation of water chemism within the agglomeration, and particularly in cities and in the vicinity of larger clusters of human settlements outside cities. The degree of transformation of the analysed waters is influenced by the hydrogeological conditions – depth of occurrence and isolation from the influence of near-surface pollution sources (Konieczyńska 1998).

4.3. Quality of the grounwaters in the area of the Łódź basin

The basic information on the quality of groundwaters in the Łódź basin is provided by the results of the regional monitoring of groundwaters conducted by the Voivodship Inspectorate for Environmental Protection in Łódź. The permanent monitoring network was organised and launched in 1992, and after a number of modifications it has been functioning until the present day. In the first year of existence, its range covered 180 wells. Twelve years later, i.e. in 2004, the number was 72. The currently conducted works cover not more than 35 objects in one study cycle, and are carried out sequentially in various fragments of the study area. Due to this, the same object is analysed once in several years. The number of Cretaceous wells subject to the study is also variable. From 1998, i.e. from the moment of the first publication of the results of regional monitoring (*Stan środowiska*… 1999) to the current moment, the number of the studied Upper Cretaceous wells changed from 4 in 2010 to 77 objects in 2001, and in the case of Lower Cretaceous wells, the number changed from 1 in 2010 to 17 in 1998. Due to the collapse of the industry, many industrial wells were eliminated and excluded from the monitoring network. Currently, the majority of intake stations supply water to cities and villages.

The waters of the Upper Cretaceous aquifer were the most frequently classified as high quality waters. Since 2008, i.e. after the change of the assessment criteria (Regulation of the Minister of the Environment of 23.07.2008), the waters have usually been determined as of good (class II) or satisfactory quality (III). Lower Cretaceous waters were assessed similarly. In contrast to the Upper Cretaceous, no cases of the highest class (I) or the lowest classes (IV and V) were recorded there.

The quality indicators which usually determined the classification of water quality as good (class II) include ammonia, phosphates, and calcium. In waters of satisfactory and unsatisfactory quality (class III and IV), such indicators were ammonia and total iron. In the case of waters from the Lower Cretaceous formations, class II was mainly determined based on phosphates and temperature, and in the lower class III – total iron.

The number of cases where a given indicator determined water classification with the indication of particular aquifers is presented in Figure 4.3. Ammonia distinguished the Upper Cretaceous aquifer of the Łódź basin in terms of the number of cases of disqualification in the lower classes. These cases more numerous than in the shallower and more prone to pollution Quaternary aquifer (Figure 4.3a). The influence of pollution sources turns out to be high enough to affect the usability of waters for consumption purposes – class III and IV, and make potential treatment unprofitable. It is worth mentioning that in the Upper Cretaceous karst-fissure aquifer, transport of pollutants is much more effective than in the porous Quaternary aquifer. The remaining indicators of presence of nutritional substances in groundwaters do not distinguish the Upper Cretaceous aquifer, but the shallowest Quaternary aquifer. In the case of nitrates and sulphates, the elimination of those indicators along with depth is observed, which is favoured by the redox conditions. Total iron and temperature, related to the natural conditions occurring in the aquifer, are more conservative. It is well visible based on the example of the Lower Cretaceous aquifer, where the depth of water intake accounted for the increased water temperature. It can be generally stated that in the assessment of quality of the waters of the Łódź basin, along with growing depth, the significance of anthropopressure indicators decreases, and that of parameters representing the geogenic environment increases. Based on the numerical values of particular groundwater quality indicators, published in 2006 and 2007 (*Stan środowiska*… 2007, 2008), a fragmentary comparative analysis of the degree of pollution of groundwaters in the area of the small and large Łódź basins can be performed. The basis of such an analysis are the maximum determined absolute values of indicators determining the qualification of water to a given quality class. The comparison of maximum values in wells in the area of the small Łódź basin with maximum values in the area of the entire large Łódź basin is presented in Table 4.4.

Table 4.4. Amount of maximum values of groundwater quality index, which determine the final class in the regional groundwater monitoring system of the Łódź voivodship in the years 2006–2007 marked out the Łódź Cretaceous small basin

Groundwater horizone	Amount of maximum values in the Łódź Cretaceous small basin in relation to all maximum cases		
	class II – good quality	class III – satisfactory quality	class IV – unsatisfactory quality
The Upper Cretaceous (K2)	7/13	8/9	5/6
The Lower Cretaceous (K1)	8/9	3/5	0/2

Source: own study on the results of ground waters regional monitoring lead by the Łódź Voivodship Inspectorate for Environmental Protection (WIOŚ 2007, 2008).

In the shallower Upper Cretaceous horizon, the significance of the small Łódź basin is high in terms of generating maximum values corresponding to lower quality classes (III and IV). In the deeper Lower Cretaceous horizon, the significance is restricted to class II, and considerably decreases in the consecutive ones.

The maximum values of the most important quality indicators for the three primary aquifers are presented in Table 4.5.

Table 4.5. Maximum values of physicochemical properties, which determine chosen class of respective aquifers in regional monitoring system of the Łódź voivodship in the year 2006–2007

Properties	Grounwater of class III			Grounwater of class IV		
	Quaternary	Upper Cretaceous	Lower Cretaceous	Quaternary	Upper Cretaceous	Lower Cretaceous
NH_4^+ [mgN/l]	0.58	0.59	0.63	1.23	1.02	1.18
NO_3^- [mgN/l]	9.08	–	7.36	11.41	19.20	–
PO_4^{3-} [mg/l]	0.45	0.39	0.36	–	0.39	–
$Fe_{og.}$ [mg/l]	2.69	3.81	1.55	5.34	1.76	1.49
Temperature [°C]	14.80	17.80	18.90	–	–	–

Source: own study on the results of ground waters regional monitoring lead by the Łódź Voivodship Inspectorate for Environmental Protection (WIOŚ 2007, 2008).

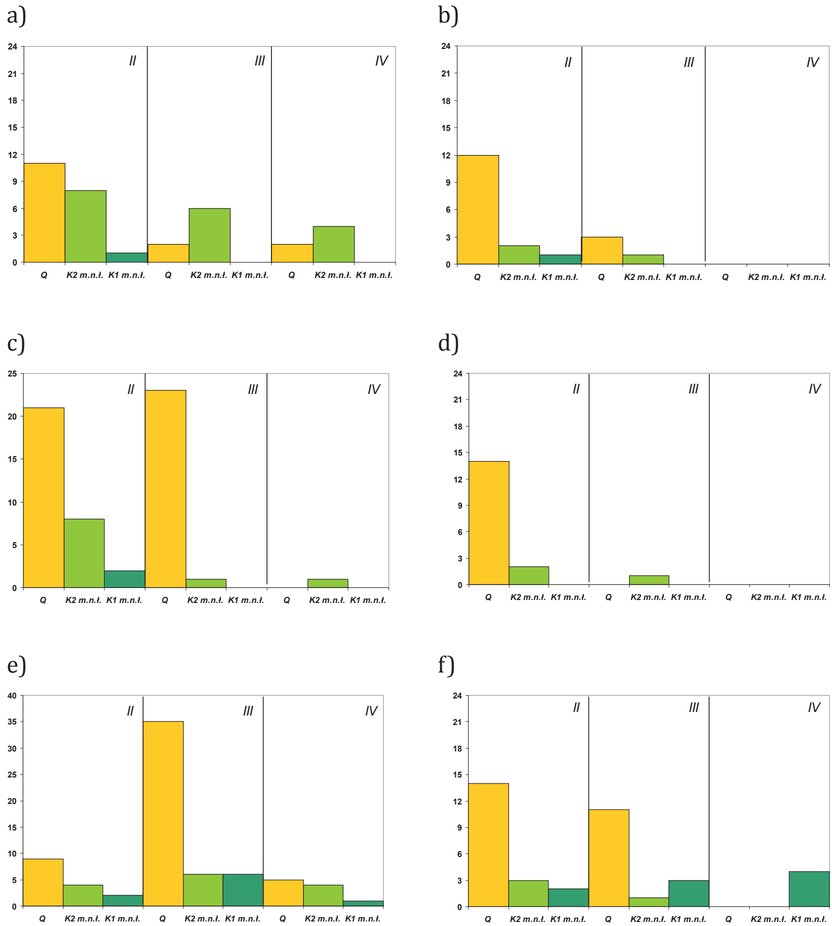

Figure 4.3. Amount of cases which qualify grounwaters to specific quality class in the area of the Łódź cretaceous small basin with regard to: a) ammonia, b) nitrate, c) phosphate, d) sulphate, e) general iron, f) temperature of water; expanations: Q – Quaternary aquifer, K2 m.n.ł. – the Upper Cretaceous aquifer of the Łódź small basin, K1 m.n.ł. – the Lower Cretaceous aquifer in the area of the Łódź cretaceous small basin

Source: own study on the results of ground waters regional monitoring lead by the Łódź Voivodship Inspectorate for Environmental Protection

The ammonium ion in the small Łódź basin reaches very similar maximums in particular aquifers. It seems that the type of pollutants represented by the indicator constitutes common pollutants, present in the rock environment over a long period of time. Results of pumping tests frequently reveal the presence in water of concentrations higher or very similar to the currently recorded ones. For example, in the municipal intake station in Ozorkowo in 1967, the ammonia ion concentration amounted to 0.2 mg N-NH_4/l (CBDH 2013), and 40 years later to 0.17 N-NH_4/l (*Stan środowiska*… 2008). Very low variability of maximum concentrations of NH_4^+ in particular aquifers (Table 4.5) is at variance with the thesis by E. Mikuła and G. Wójcik (1995) stating that too high ammonia concentrations in the groundwaters of the Łódź basin are partially responsible for the presence of brown coals in the Neogene aquifers. The study by the Laboratory of Geology of the University of Łódź (Ziułkiewicz 2003a) showed that in the Neogene aquifers, the maximum concentrations of NH_4^+ vary from 0.24 mg N-NH_4/l in Pliocene sands to 0.77 mg N-NH_4/l in Miocene sands with admixtures of lignite. The Neogene aquifer in the Łódź basin has a very extensive range, composed of isolated lens filling depressions in the uppermost layer of Cretaceous formations. The formations are frequently isolated from the neighbouring aquifers with weakly permeable rocks. Therefore, the geogenic origin of the ammonia can only be considered in relation to very limited parts of the water bearing structures of the basin and its overburden.

The total iron values presented in Table 4.5 suggest much more stable conditions of its occurrence in the Lower Cretaceous aquifer at lower concentrations than those in the shallower aquifers. The presence of high quantities of nitrates in wells in both of the aquifers is disturbing. This is caused by the injection of pollutants through the zone surrounding the well opening, or through the well itself. Such a possibility was discovered during research works on Upper Cretaceous intakes functioning in the southern part of the Łódź agglomeration (Ziułkiewicz 2013). Polluted groundwaters penetrate the intake through its untight casing. They flood its bottom fragment up to the height of the casing of the well opening through which they overflow. In order to retain NO_3^- ions in confined waters, they need to be oxidised. At depths of more than 100 m, this can only be ensured by the structure of the well opening. Denitrification begins when the Eh value falls below +220mV/+250mV, depending on the water reaction. The study by Ziułkiewicz (2003a, 2013) showed that in waters extracted from the Upper Cretaceous aquifer, Eh values vary from –34 mV to –90 mV. Therefore, the presence of nitrates in such waters must render their fresh pollution, because the determined ions did not have time to decompose. The results of the annual analyses revealed that after more than one year, the concentrations of nitrates can fall below the identifiability threshold. This suggests an incidental or seasonal character of this type of pollution.

An evident manifestation of the effect of the geogenic factor on groundwater quality is water temperature. Exploitation covers aquifers located in the area of influence of the heat energy from the middle of the Earth. Some of the Lower Cretaceous water intakes in Łódź are geothermal waters (Wiktorowicz 2010). The presence of warm waters in shallower aquifers results from the mixing of the warmer waters of deeper circulation with cooler shallower waters, as was documented in the area of Ozorkowo (Kolago 1957). In sporadic cases, it can also be a result of physical contamination, as documented in Łódź in a Quaternary groundwater intake in Nowe Sady (Ziułkiewicz 2003a), where hot waters from the untight installation flew in to the intake causing an interesting phenomenon of thermal inversion of waters in the well opening.

Frequent organisational changes in the existing regional monitoring network, and evolution of legal provisions, including water quality criteria, largely limit the possibility of tracing changes in the quality of Cretaceous groundwaters at a long temporal scale and wider spatial range. Out of more than 150 study sites, only sporadic cases of wells with twenty-year observation period remain (1992–2012). Earlier data are not always useful, because they were obtained by various economic entities and governmental institutions in various research scopes, and with the application of different measurement and analysis methods, as discussed more extensively by Ziułkiewicz (2003a). One of the methods of identification of the physical and chemical image of groundwaters in a long time perspective is reaching for archival study results, obtained during pumping tests, and their comparison with the results of the current study, as in the above example for the intake station in Ozorkowo. Another way is to obtain access to results of research of particular industries, e.g. ZWiK (water supply and sewage management services), or heat energy plants in Łódź (Figure 4.4). The latter data permit tracing changes in the chemism of "Upper Cretaceous" waters during the development and later diminishment of the so-called Łódź depression cone, based on the example of the intake in EC II. The inflow of waters from other parts of the Upper Cretaceous aquifer, which supplemented a long-lasting deficit, resulted in only slight changes in some of the hydrochemical parameters: dry residue (Figure 4.4a) and sodium and chloride ions (Figure 4.4c), but not total hardness (Figure 4.4b). An increase in the concentration of sulphates occurring during the time suggests the progressing quality degradation in the centre of Łódź (Figure 4.4c). Based on results of analyses by ZWiK Łódź, supplemented with own observations from the years 1999–2000 (Ziułkiewicz 2006), in shallower intakes located in the Sub-Cainozoic zones of outcrops of both of the Cretaceous horizons, the dynamics of changes in the parameters representing anthropopressure in the city were determined to be considerably higher than outside the city (Figure 4.5). In the case discussed, these are chlorides, a very active water migrant, and a sensitive indicator of economic-household and transportation related pollution.

The depth range of the pollution zone, covering particular usable aquifers of the Łódź basin to various degrees, requires dedicated analyses. They should permit an insight into changes in the hydrochemical image of waters along with the depth of a given water bearing structure, in this case the Łódź basin and its Cainozoic overburden. This requires the selection a compact complex of wells

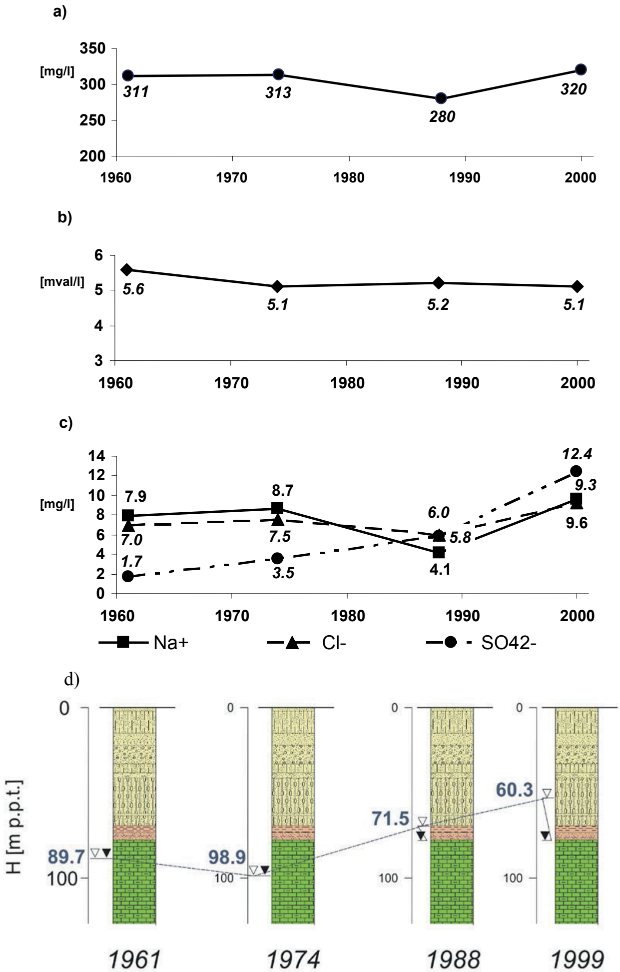

Figure 4.4. Changes selected hydrochemical properties of grounwater from upper cretaceous aquifer from wells which are situated in power-heating plant no. 2 in Łódź: a) dry residue, b) total hardness, c) selected ions, d) grounwater level in the upper cretaceous aquifer on the background of geological profile of the well

Source: own study on the results of wells monitoring in power-heating no. 2 (1960–1990) and own investigation (2000)

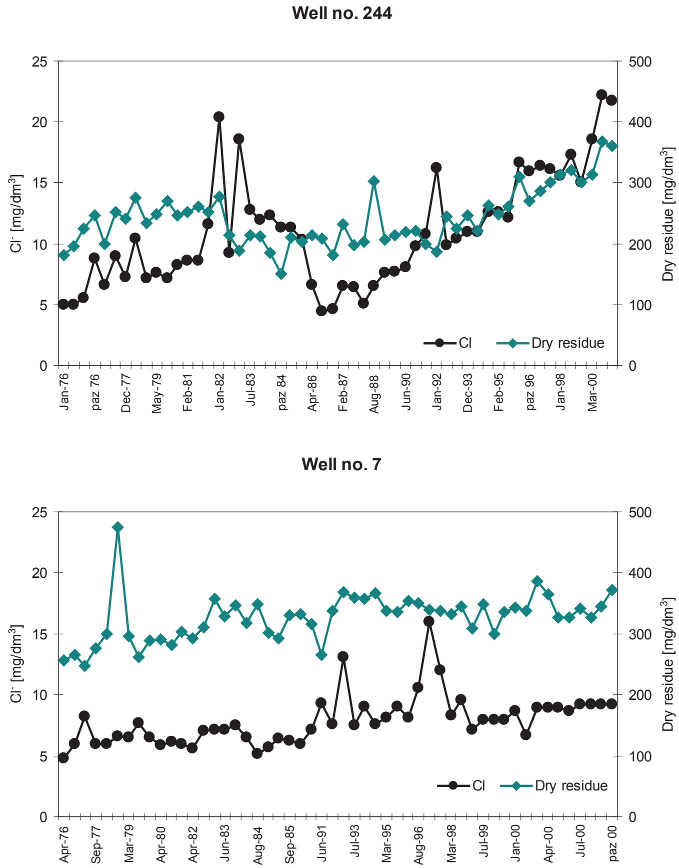

Figure 4.5. Changes of chloride concentration in selected wells reaching quaternary aquifer in the Łódź (well no. 244) and beyond city (well no. 7)

Source: based on M. Ziułkiewicz (2003a)

located in a restricted area, i.e. the selection of a research polygon representing a specified local hydrogeological context. Due to the lack of earlier coherent research approaches to the issue, evidenced by M. Ziułkiewicz (2003b), in the years 1999–2000, observations were conducted concerning changes in groundwaters chemism in the vertical profile of geological formations in the area of the Łódź agglomeration, i.e. within the small Łódź basin. In the W-E cross-section of this hydrogeological unit (Figure 4.2), a regional alimentation zone can be distinguished in the eastern part of the Łódź agglomeration, as well as a discharge zone under the central part of the agglomeration, and a drainage zone in its western and northern part. The research was conducted on three polygons selected on the line Rzgów–Zgierz running along the synclinic axis, i.e. in the water discharge zone. The results show considerable hydrochemical changes within the Quaternary and Neogene aquifers in the area of the city. They involve a drastic increase in water mineralisation and concentrations of sodium, chlorides, and sulphates, as reflected in the hydrochemical classification (multi-ion character of the type) (Figure 4.6). This way, anthropopressure intensified the natural mineralisation inversion of the waters of the Łódź basin and its Cainozoic overburden. Changes in water quality documented in intakes supplying water to the city are disturbing, because they also cover the shallowest aquifer within the boundaries of the zone of direct protection of the intakes. The determined pollution of groundwaters is related to the residential housing development in the vicinity of the intake without the application of relevant sewage management solutions. The regional monitoring covering the Upper Cretaceous well in this intake documented an increase in the concentration of sulphates from a level below the identifiability threshold in 1993 (Report 3, 1994) to do 58.4 mg SO_4^{2-}/l five years later (Report 8, 2000). At the same time, also an increase in the ammonia ion concentration was recorded from 0.06 mg N-NH_4/l (1996) (Report 5, 1996) to 0.44 mg N-NH_4/l 10 years later (Report on the state of the environment, 2007).

Bad sanitary solutions are a cause of groundwater degradation not only in the area of direct protection of the intake, but also in the nature reserve including springs among its objects of protection. The Struga Dobieszkowska reserve is located within the Łódź agglomeration, in the Łódź Hills landscape park. Several tens of natural outflows of groundwaters function in the park, draining the upper part of the thicker intermorainic horizon of the Quaternary aquifer (Ziułkiewicz 2005). The study showed that the springs draining the uppermost part of the aquifer are substantially more affected by anthropopressure than objects fed by deeper parts of the aquifer (Table 4.6) (Żelazna-Wieczorek et al. 2010). This hydrochemical variability is confirmed in the algological analysis of the waterhead niches.

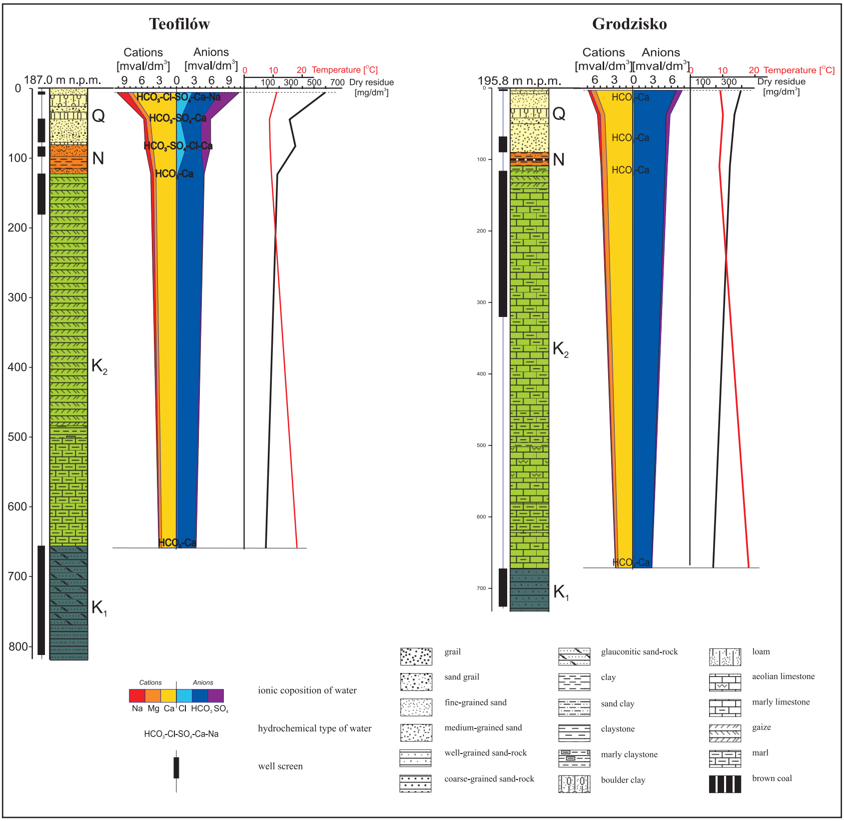

Figure 4.6. Hydrochemical profiles of the Łódź cretaceous small basin and its Cainozoic overlayer sediments on the Teofilów polygone (the city) and the Grodzisko polygone (beyond city)

Source: based on M. Ziułkiewicz (2003b)

Table 4.6. Chosen hydrochemical properties of spring waters in the Dobieszków Stream Reserve

Properties	Springs supply from upper part of aquifer	Springs supply from deeper part of aquifer
Dry residue [mg/l]	458.0	300.0
Cl^- [mg/l]	22.0	10.5
NO_3^- [mg/l]	43.0	8.0
PO_4^{3-} [mg/l]	0.41	0.27

Source: J. Żelazna-Wieczorek et al. (2010).

The state represented by the springs in the nature reserve is symptomatic for a vast majority of such objects under research by the Laboratory of Geology of the University of Łódź, beginning from 1993. The analysis of the factors causing the degradation of water resources (Nachlik 2004), conducted in areas outside the city in the northern part of the Łódź agglomeration, showed the contribution of the municipal services of communes higher than that of the present agricultural activity (Ziułkiewicz 2012, Górecki 2012).

An indirect effect of strong contamination of the groundwaters of shallow circulation, including areas of alimentation of the Cretaceous aquifers of the Łódź basin, is the quality of surface waters. A study conducted in the years 2009–2010 in the catchment of the Upper Moszczenica River (Ziułkiewicz 2012) revealed a high degree of the river's pollution, whereas the river has no concentrated pollution sources along its course. Such a situation results in a considerable eutrophication of the retention reservoir in Stryków (Figure 4.7). It fulfils the recreational function for the inhabitants of Strykowo. The function cannot be executed, however, also due to the bacteriological pollution of the Moszczenica River. The analysis of the results of hydrochemical research showed a curious disproportion between COD and BOD (Table 4.7). This was the first symptom of the presence in the analysed river waters of pesticides in amounts blocking the activity of microorganisms, and therefore biochemical transformations of organic pollutants. Such a situation contributes to a substantial reduction of the river's self-cleaning processes already in its upper section. Works executed at a further stage of research by the Department of Microbiology and Biotechnology of the Faculty of Biology and Environmental Protection of the University of Łódź showed that pesticides are released from the waste repository of a former State Agricultural Farm PGR (Szewczyk 2011). This type of differences between both of the oxygen indicators do not occur in other simultaneously studied rivers in the vicinity of Łódź not receiving sewage from the Łódź agglomeration (Table 4.7). Migration of pollutants towards the river occurs by means of groundwaters. Their exchange time, determined based on the curve of drying up of the surrounding springs, varies from 2 cycles per year to 1 cycle over two years (Ziułkiewicz 2005). High differences in the regime of springs located very close to each other, and considerable disproportions in the development of the water table of the first aquifer, e.g. in cross sections of the Młynówka River valley – a left-bank tributary of the Upper Moszczenica River, suggest glacitectonic disturbances in the bedrock (Klatkowa 1996). In such circumstances, natural barriers in the form of layers of weakly permeable formations are untight. Therefore, the pollutants from the near-surface zone can be quickly transported deep into the rock structures. Among other specific substances causing water contamination, the results of the regional monitoring reveal the incidental presence of detergents in various intakes, including the Lower Cretaceous aquifer. They did not reach the zone of alimentation of this aquifer, however. It was determined that the time of discharge of waters in Lower Cretaceous sands, estimated by means of isotope methods, amounts to 410 years (Ziułkiewicz 2003a, b). The age of pollution resulting from artificial chemical synthesis is much lower. Therefore, the pollutants must have appeared through underground flow.

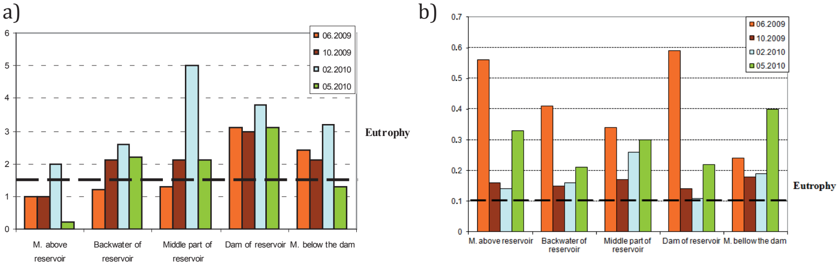

Figure 4.7. Total nitrogen (a) and total phosphorus (b) concentrations in the waters of the Stryków reservoir and in the waters of Moszczenica River above and below them. Signed limiting value of both biogenic property of waters, which is used in Poland to estimate the eutrophy of inland stand waters

Source: Decree of the Minister of Environment of December 23, 2002 (*Rozporządzenie*... 2003)

Table 4.7. COD and BOD values of the Moszczenica waters in the section among springs and the Stryków city, and another small rivers of the Łódź neighbourhood

Parameter [mg O_2/l]	Sample points on the Moszczenica river course: below springs	Skoszewy village	Cesarka village	above the Stryków reservoir	below the Stryków reservoir	Another rivers: Miazga River above Andrzejów village	Morga River in the Stare Koluszki village	Mrożyca River in the Marianów Kołacki village
COD	10.3	9.3	5.2	9.7	6.2	9.0	2.9	3.7
BOD	0	1	0	1	0	3	10	9

Source: M. Ziułkiewicz (2012).

4.4. Conclusions

The Łódź basin, and particularly its north-eastern fragment, has a very high economic importance in terms of abundance, still good quality of groundwaters, and their availability in the watershed zone. More than 150 years of anthropogenic pressure is currently only recorded in the qualitative aspect of groundwaters, affected by both the anthropopressure factors and geogenic conditions. The results of the regional monitoring, supplemented with own research of the Laboratory of Geology of the University of Łódź, show substantial pollution of shallow aquifers. This is determined by a number of factors, not always related to urban landscape. Due to their natural conditions, deeper Cretaceous aquifers are much less polluted, although the pressure is higher within the small Łódź basin than outside of it. This relates to the forms and intensity of land management, particularly in zones of alimentation of aquifers. The quality of groundwaters of the Łódź basin is also determined by geogenic factors, as exemplified by the Lower Cretaceous aquifer, locally of geothermal character.

Contaminants penetrating groundwaters lead to the hydrochemical differentiation of waters in the same aquifer, particularly distinguishing its uppermost layer. Moreover, they cause the degradation of other elements of the hydrosphere used by man, such as rivers right from their springs, and waters retained in usually small reservoirs. A change in the conditions of transport of pollutants results in the activation of some of their forms, e.g. biogenic substances, and leads to secondary changes in the quality of stagnant waters.

From the perspective of time and area in which the Laboratory of Geology of the University of Łódź conducted research on groundwaters in the years 1993–2013, a diminishment of old threats within cities, and activation of new ones outside of cities is observed, often in areas of alimentation of Cretaceous aquifers in the eastern part of the Łódź agglomeration. In the conditions of limited possibilities of registration of groundwater quality by the currently functioning regional monitoring system, and total withdrawal of elements of the national monitoring from the Łódź region, the functioning of our unit is supplemented by the system of identification and registration of groundwater quality in the region of the small Łódź basin. An example is the recording in summer of the current year of pollution with petroleum derivatives of a usable aquifer in the southern suburbs of Łódź. Works on the determination of the scale of the threat for the surrounding intakes have been undertaken.

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