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Lake surface changes of the Osa River catchment, (northern Poland), 1900–2010

Katarzyna Kubiak-Wójcicka [a], Karol Piątkowski[a] and Włodzimierz Waldemar Juśkiewicz [b,c,d]

[a]Faculty of Earth Sciences, Department of Hydrology and Water Management, Nicolaus Copernicus University in Toruń, Toruń, Poland; [b]Polish Academy of Sciences, Institute of Geography and Spatial Organization, Toruń, Poland; [c]Faculty of Social and Technical Sciences, Cuiavian University, Włocławek, Poland; [d]Centre for Underwater Archaeology, Nicolaus Copernicus University in Toruń, Toruń, Poland

ABSTRACT
The study objective was to prepare a quantitative inventory of lakes and to assess their long-term changes. The research area included the Osa river basin (northern Poland), which is located in a lake district. The research was based on historical cartographic materials published in 1900-1947 (German 1:25,000 'Messtischblatt' topographic maps) and modern topographic maps from 2010 (The 1:50,000 Digital Map of the Hydrographic Division of Poland [MPHP]. The number of lakes increased from 173 to 235, while the total surface area of the lakes fell by 107.55 ha. The largest number of lakes belonged to the 1.0-5.0 ha range on both MPHP and Messtischblatt maps. It was in this range that the largest increase in number of lakes and lake area relative to the historical maps was found. A significant reduction in area of lakes was recorded in the group of lakes with an area from 50 to 100 ha.

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Lakes; area changes; reclamation; the Osa River catchment; Poland

1. Introduction

Lakes are landscape elements that are very vulnerable to environmental changes. The pace of such shifts varies depending on climate changes as well as anthropogenic activities (Bai et al., 2011; Naga Kumar et al., 2016; Zhang et al., 2019). Water bodies and lakes occupy a small part of the Earth's surface (~3.7%), but are key features of the hydrological cycle (Verpoorter et al., 2014). Various sources of information were used to determine the number of lakes on the planet and their surface areas, including national inventories and descriptions, estimated data and cartographic sources (Downing et al., 2006; Lehner & Döll, 2004). As repeatedly emphasized, the accuracy of the results depended on many factors resulting from the availability and accuracy of the source materials (topographic maps, aerial and satellite photos) (Pekel et al., 2016). The development of remote sensing and access to high-resolution satellite data brought studies that include lakes of less than 1 km^2, or even smaller than 0.01 km^2 (Busker et al., 2019). The uneven distribution of water resources in the world, combined with climate fluctuations and anthropogenic factors, has caused special attention to be paid to changes in regional and local surface areas of lakes (Smith et al., 2002; Yao et al., 2018; Policelli et al., 2018). Lakes are in most cases, the changes consist in areas decreasing as a result of human activities, e.g. land development (Chen et al., 2018; Grzywna & Sender, 2017; Povilaitis & Querner, 2008), change in land use (Jakubínský & Báčová, 2013) and others (Hara et al., 2014; Kubiak-Wójcicka & Solarczyk, 2014; Naga Kumar et al., 2016; Meyer et al., 2017; Molewski & Juśkiewicz, 2018).

The increasing changes in climate over the past decades have led to more attention being paid to recognizing the complexity of interactions between changes in climatic conditions (mainly precipitation and air temperature) and other anthropogenic factors. Knowledge of these factors will help determine the dynamics of changes in lake area over the coming few decades. Understanding the nature of lake changes on a regional and local scale is important for long-term sustainable development. This study has significant implications for improving support for decisions on water-resource management strategies and land-use planning within a given region (Zhang et al., 2019).

Poland is a lowland country, the most part of which consists of the lowland of the eastern part of the Central European Lowland. Lakes are the main landscape element in northern Poland, which results from the fact that this area was covered by the Vistula glaciation. According to Choiński (2006), there are approximately 7,000 natural lakes of more than 1 ha in Poland. The largest accumulation of lakes is located in the areas of the Masurian Lakeland, the Pomeranian Lakeland and the Greater Poland and Kuyavian Lakeland.

CONTACT Włodzimierz Juśkiewicz ✉ wwj@protonmail.ch Polish Academy of Sciences, Institute of Geography and Spatial Organization, Kopernika 19 87–100, Toruń, Poland

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The first study that widely analyzed lake area changes was performed by Kalinowska (1961). That study proved that two thirds of lake area in northern Poland has disappeared since the Late Holocene. The main reason for lake shrinkage has been natural factors, including overgrowing, lake basins being filled with sediments, and periodically reduced feeding. In the last few centuries, the disappearance of lakes has increasingly been caused by anthropogenic factors. Many studies used an analysis of historic maps, which are a great source of knowledge on environment (Kaniecki, 2011; Mackovčin & Jurek, 2015). Examples of such studies include papers written on particular regions of Poland, e.g. the Masurian Lakeland (Marszelewski & Adamczyk, 2004), the Pomeranian Lakeland (Ptak, 2013), the Greater Poland and Kuyavian Lakeland (Ptak, 2012) and particular catchments (Juszczak & Kędziora, 2003; Kubiak-Wójcicka & Lewandowska, 2014).

Map analysis allows for the reconstruction of the hydrographic network from before the time when anthropogenic changes were introduced. In the opinion of many authors, the Messtischblatt maps are very accurate and precise for the times when they were developed. Therefore, they have been used very often as source material for reconstructions (Barabach, 2012; Chudziak et al., 2014; Kowalewski, 2013; Ptak, 2017). In recent years in Poland, the hydrographic network has increasingly often been subject to analysis historical in order to be categorized as inland flowing or standing water in the light of the Water Law Act (Kubiak-Wójcicka et al., 2017; Kubiak-Wójcicka & Marszelewski, 2012).

2. Materials and methods

Lake-area changes have most often been analyzed within catchments. A catchment is a geographical functional region widely used in hydrology and ecology and recommended as the proper unit for planning and usage of water resources (Steiner et al., 2000). The choice of the Osa River catchment was dictated by its geographical location in northern Poland. The catchment is located between the Masurian Lakeland, which is the area of greatest density of lakes in Poland, and the Lower Vistula Valley, which has been extensively regulated.

The aim of the paper is to present the scale and trend of changes in the area of lakes located in the Osa River catchment over the last 100 years. The study was conducted on the basis of cartographic materials published between the beginning of the twentieth century (e.g. the Messtischblatt) and the present (the Digital Map of Hydrographic Division of Poland, also referred to as the MPHP). Archival topographic maps are the basic source of spatial information about the location and the shoreline of water reservoirs, especially considering the possibilities offered by their processing and analysis in the Geographical Information System (GIS) (Brůna et al., 2010; Frajer & Fiedor, 2018; Pavelková et al., 2016). Appropriate maps were selected for their accuracy (scale) and the degree of detail they provided. The research procedure used to determine changes in lake area within the study area followed these stages:

(1) Gathering information and reviewing existing maps from the area covering the Osa river basin over the last 150 years
(2) Selection of maps for comparing lake surface changes
(3) Database creation
(4) Analysis of results.

The calculation starting point was the inventory of all lakes present on the Digital Map of the Hydrographic Division of Poland (MPHP) from 2010, at a scale of 1:50,000 (https://dane.gov.pl/dataset/869,komputerowa-mapa-podziau-hydrograficznego-polski/resource/2947/table). It is a uniform, continuous database of hydrographic data for the area of Poland, which contains a collection of GIS vector information layers (ArcInfo) and full geometric and descriptive characteristics of the water network and the catchment. Due to the large number of lakes smaller than 1 ha, the comparative study only included objects larger than or equal to 1 ha and present on both the MPHP and the Messtischblatt maps.

It was possible to determine lake-area changes in the Osa River catchment in the last 100 years by using the German 1:25,000 topographic maps known as the ‘Messtischblatt’. Those maps were released in the years 1900–1947 and constituted the most accurate cartographic material created in that period. The original German maps are held in the cartographic collections of the Faculty of Earth Sciences and Spatial Management of Nicolaus Copernicus University in Toruń, and are available from the website of the Map of Western Poland Archive [*Archiwum Map Zachodniej Polski*] (http://mapy.amzp.pl/maps.shtml). The Osa River catchment is covered by 28 German map sheets (Figure 1). The German topographic maps were scanned and calibrated in the ArcMap application software on the basis of a grid of fixed points (most often crossroads). All the maps (historical and contemporary) were converted to a single coordinate system (ETRS_1989_UWPP_1992) which was the basis for digitizing the hydrographic objects in two time perspectives. The data-processing methodology is shown in Figure 2.

All lakes inventoried on the historical and modern maps have been grouped by size class: 1–5 ha, 5–10 ha, 10–20 ha, 20–50 ha, 50–100 ha and 100–1000 ha. Then, the changes in lake area within individual

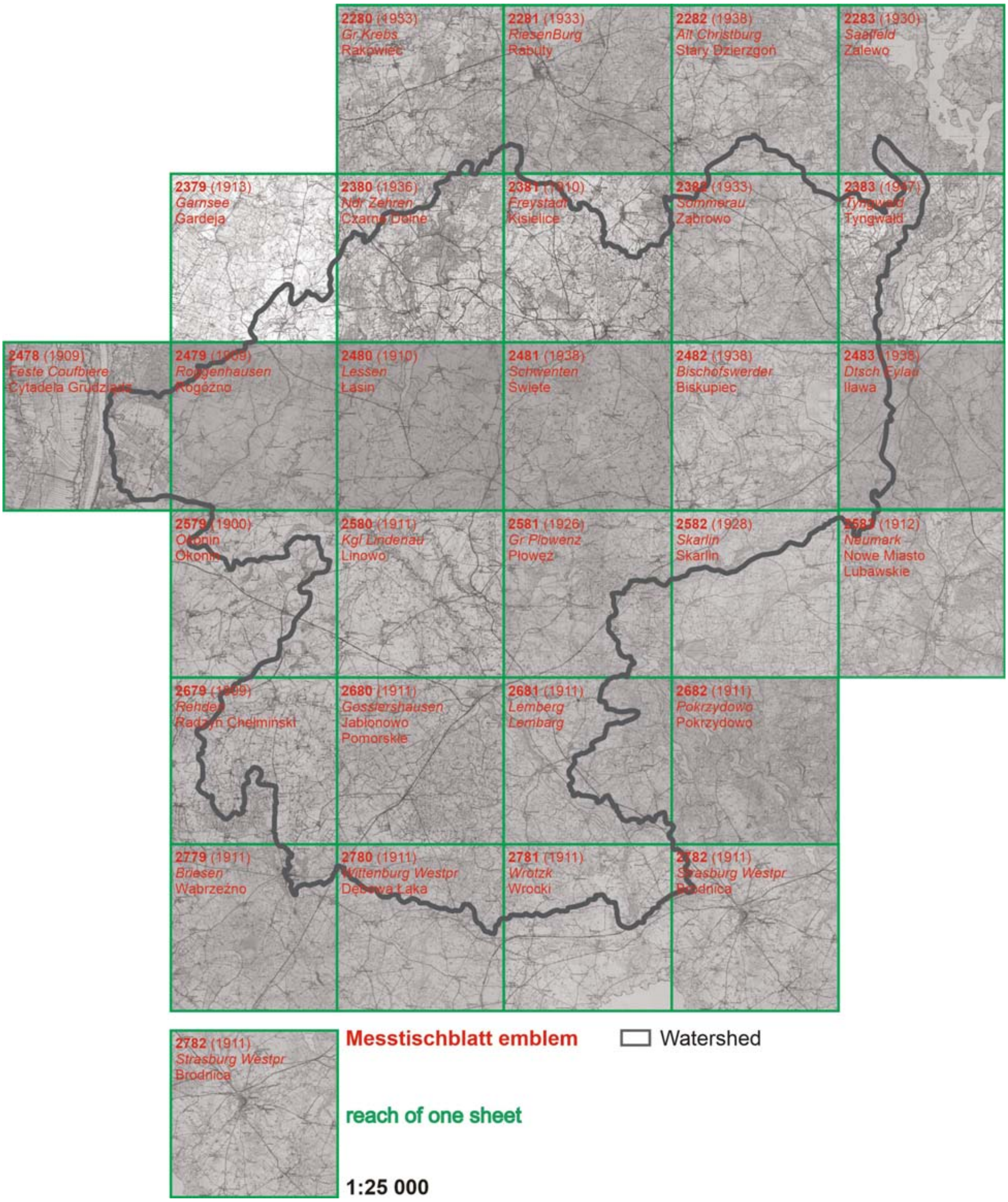

Figure 1. Range of Messtischblatt sheets within the Osa catchment.

lake-surface divisions were compared. The analysis of area changes covers all lakes whose area was greater than 1 ha either on both the MPHP and the Messtischblatt map or on just one. Area changes were calculated on the basis of differences between lake area on the MPHP map and on the Messtischblatt map and expressed as the current lake area as a percentage of its historical area. Depending on the achieved percentage change, change ranges were set. Changes were assumed to be zero for increases or decreases of 5% as of 2010, while areal increases and decreases were determined in the ranges 5–10%, 10–20%, 20–50% and over 50% as of 2010 maps.

The data obtained from cartographic sources were supplemented by statistical analysis of meteorological and hydrological data. Climate change was determined using data on annual sums of precipitation at three meteorological stations (Prabuty, Gardeja and Radzyń Chełmiński) and annual average air temperatures (Prabuty only). Hydrological changes within the catchment were determined based on analysis of average annual discharge of the Osa River at the Rogóźno

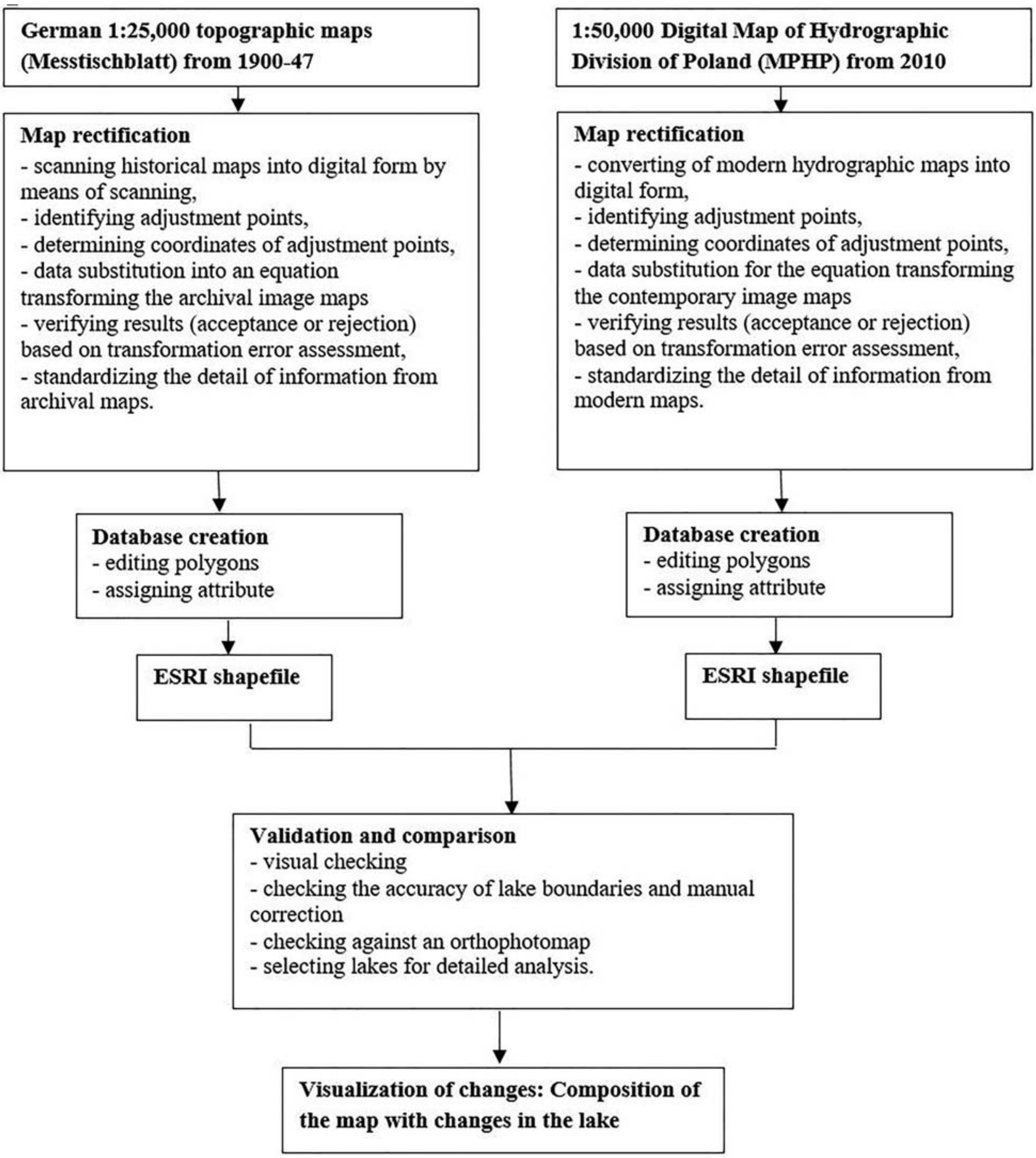

Figure 2. Data-processing methodology.

hydrological station. Trends in meteorological elements were determined by statistical methods by linear regression of annual precipitation sums and annual discharges of the Osa River. The data come from the Institute of Meteorology and Water Management – National Research Institute and includes the longest measurement series for the years 1951–2015. Analysis of the mentioned data determined the extent to which climate changes affected the area of the lakes.

3. Study area

The research area is the Osa catchment of northern Poland. The basin covers 1,606.27 km^2. The River Osa is a second-order watercourse and a right tributary of the Vistula river (Figure 1). The Osa takes its origin in the Parkun lake and flows into the Vistula in the 842nd kilometre of its course (north of the town of Grudziądz). The Osa's length is 109.84 km. The Osa's major tributaries include the rivers Osówka, Gać, Kakaj, Młynówka, Lutryna, Łasinka, Gardęga and Pręczawa (Figure 3).

The relief of the research area was shaped mainly during the disappearance of the last ice sheet during the main stadial of the Vistula glaciation (Kordowski et al., 2014). The area's topographic peaks are located on the southern part of a plateau, on thrust-moraine hills of up to 130 m a.s.l. The parts of the Vistula flood plain are lowest, at about 22 m a.s.l. There are deposits from the Weichselian glaciation on the terrain surface. These are primarily tills, occasionally sands and gravels. The predominant climate of the research area is moderate, and transitional between marine and continental. In the Osa basin, the average annual sum precipitation is low, at about 600 mm. Rainfall is lowest in February, and highest in July.

Arable lands dominate in terms of land use, accounting for almost 70% of the catchment area. Forests occupy small areas of glacial sand, gravel, outwash and end moraines. They cover 14.4% of the area. The few forest complexes are dispersed, forming enclaves among arable lands. Meadows occupy about 10%, swamps 1.78%, and buildings (mainly dispersed) cover 1.28% of the area of the Osa catchment area (Figure 2). The surface of lakes together with artificial fish ponds covers about 3% of the catchment area.

4. Results and discussion

4.1. Meteorological and hydrological conditions in the Osa catchment

Of the natural causes of lake shrinkage, the most significant are changes in climatic conditions, and particularly in air temperature and precipitation. Precipitation in the Osa catchment was described for three meteorological stations (Prabuty, Gardeja and Radzyń Chełmiński), for which data from 1951–2015 were obtained (Figure 4). The annual average sums of precipitation in the period 1951–2015 ranged from 549.6 mm to 618.1 mm. The highest rainfall was recorded in Prabuty, and the lowest in Radzyń Chełmiński. Annual sums of precipitation differed significantly between stations within particular years. An analysis of sums of precipitation over the 65-year

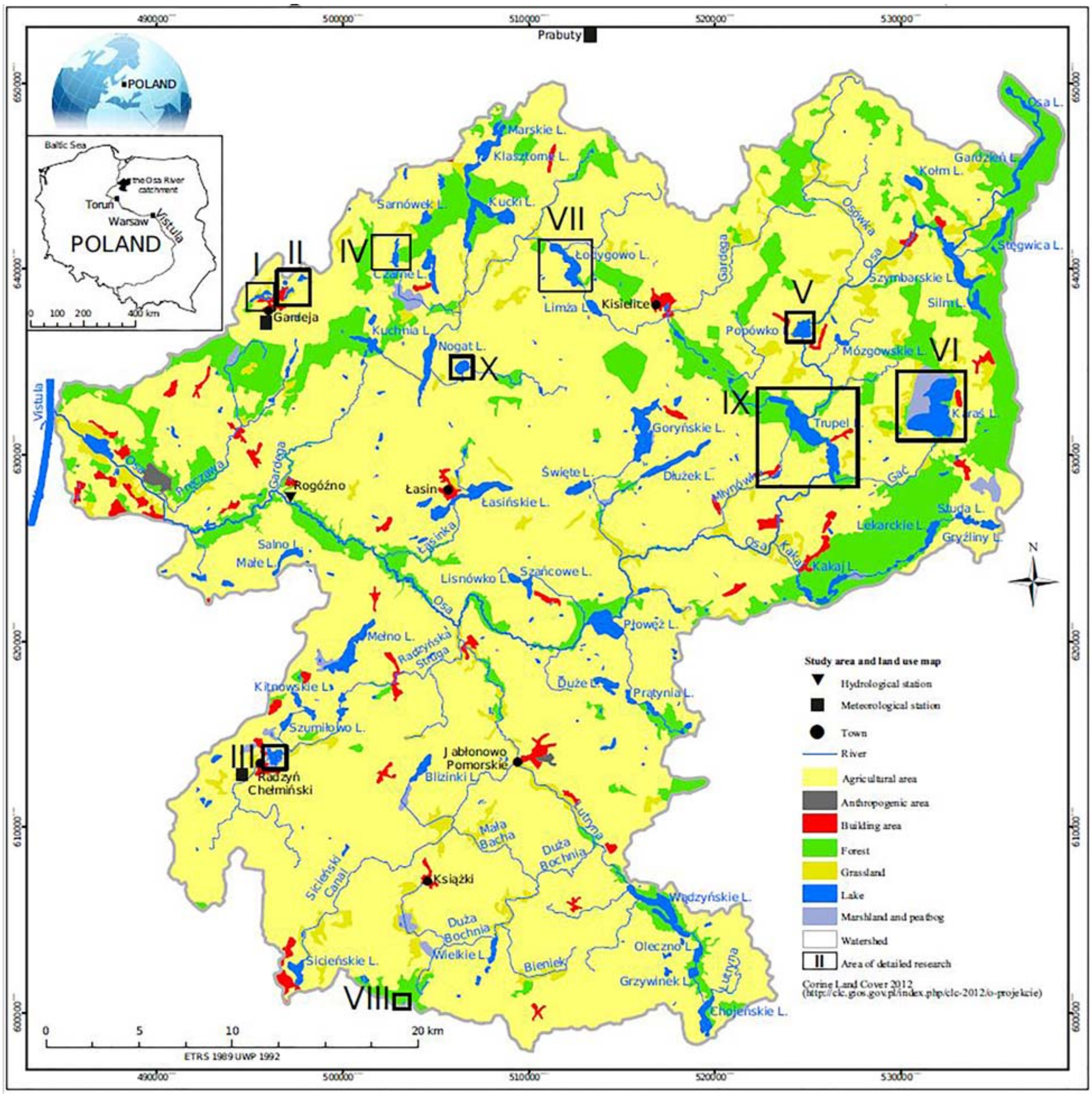

Figure 3. Study area and land-use map by Corine Land Cover, 2012 (http://clc.gios.gov.pl/index.php/clc-2012/o-projekcie).

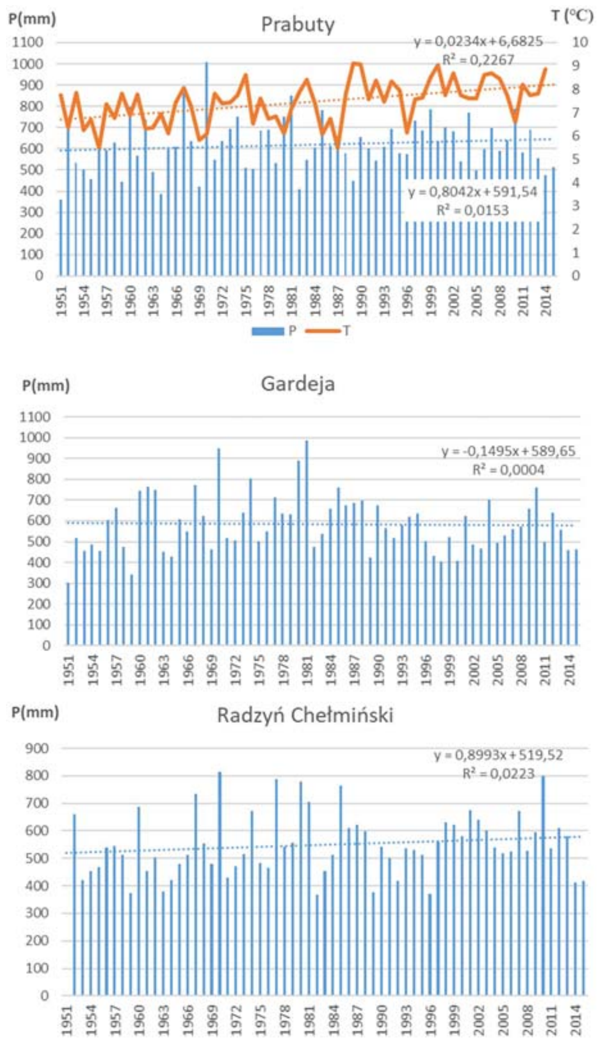

Figure 4. Annual precipitations and average air temperatures at selected meteorological stations (based on data from the Institute of Meteorology and Water Management – National Research Institute).

period showed an upward trend in Prabuty and Radzyń Chełmiński, while at the Gardeja station the trend was downward. The values were not statistically significant. Analysis of the annual sums of precipitation in the shorter research period of 1966–2015 showed a clear downward trend in precipitation at all three meteorological stations (Kubiak-Wójcicka, 2020).

The actual feeding of lakes with atmospheric precipitation depends on the amount of losses, especially through evaporation. Amount of evaporation depends primarily on air temperature. Of the three meteorological stations, the annual average air temperatures for the years 1951–2014 were recorded only at the station in Prabuty. In the research period, the air temperature in Prabuty increased by an average of 0.23°C every 10 years.

Alongside changes in precipitation and air temperature, changes in the Osa River discharge at the Rogóźno station are seen in the comparable period of 1951–2015. The average annual discharge of the Osa ranged from 1.36 m^3/s to 9.7 m^3/s. The long-term average discharge was 4.5 m^3/s. Analysis of annual discharges over the 65-year period revealed a downward trend. The changes in discharges in the river were associated with the course, distribution and extent of precipitation in specific years. According to the research by K. Kubiak-Wójcicka (2020) for a shorter observation period (1966–2015), the discharges of the Osa in the Rogóźno profile showed a much greater downward trend than they did for 1951–2015, which may attest to water resources decreasing within the basin.

4.2. Changes in lake area

4.2.1. Lakes of less than 1 ha

The analysis of the cartographic materials within the Osa's catchment area revealed that the total number of lakes present on the 2010 MPHP map is 1,079. Those lakes cover 4727.11 ha, which is 2.94% of the catchment's area. Most of the lakes (as many as 844) are small, with an area of less than 1 ha. The total area of such lakes comprises 7% of all inventoried lakes in the catchment. The analysis of the German maps revealed that there were 6,085 lakes covering a total area of 4,900.33 ha. Most of the lakes (as many as 5,912, i.e. 97% of the lakes) were smaller than 1 ha. Those lakes would take approximately 8% of total lakes area in the Osa's catchment. Such a large change in the number of the lakes smaller than 1 ha in the period of 100 years has both natural and anthropogenic causes. In most studies, lakes smaller than 1 ha are neglected (Choiński, 2006), which does not mean that their existence and significance to the landscape is negligible (Ignatius & Jones, 2014).

4.2.2. Lakes of more than 1 ha

On the 2010 MPHP maps, there were 235 lakes larger or equal to 1 ha inventoried in the Osa's catchment, totaling 4,402.71 ha (2.74% of the catchment) (Table 1). Half of the area of all water basins is covered by lakes bigger than 100 ha. There are twelve such lakes in the catchment. In turn, the German maps have an inventory of 173 lakes larger than 1 ha totaling 4,510.26 ha (Table 1). There were ten such lakes, and they covered approximately 48.7% of total lake area (Figure 5 and Table 2).

The 1.0–5.0 ha range is the most abundant on both the MPHP and Messtischblatt maps. Also, the largest change in the number of lakes was recorded in this range. The number of lakes in the range from 1.0 to 5.0 ha increased by 88% on the 2010 map relative to the 1900–1947 maps. In the remaining size ranges, the increase or decrease was not as large, and did not exceed 20%. In order to determine changes in lake surface area over time, lake areas on the 2010 MPHP map were compared to lake areas on the

Table 1. Number and area of lakes inventoried on the MPHP map (2010).

Size range in ha	Number of lakes	% of total number	Lakes' area in ha	% of total area of all lakes
1–5	141	60.00	282.02	6.41
5–10	24	10.21	171.22	3.89
10–20	25	10.64	353.09	8.02
20–50	23	9.79	713.68	16.21
50–100	10	4.26	647.46	14.71
100–1000	12	5.11	2,235.24	50.77
Total	**235**	**100**	**4,402.71**	**100**

Table 2. Number and area of lakes in the Osa catchment according to the Messtischblatt maps (1900–1947).

Size range in ha	Number of lakes	% of total number	Lakes' area in ha	% of total area of all lakes
1–5	75	43.35	167.03	3.70
5–10	27	15.61	190.53	4.23
10–20	22	12.72	318.79	7.07
20–50	27	15.61	830.01	18.40
50–100	12	6.94	807.95	17.91
100–1000	10	5.78	2,195.95	48.69
Total	**173**	**100**	**4,510.26**	**100**

German maps from the beginning of the twentieth century. The analysis of a general trend of lake surface area change over 100 years showed that the total lake area decreased from 4,510.26 ha (1900–1947) to 4,402.71 ha (2010) – that is, by 107.55 ha or 2.38%. According to Choiński (2006), lake area decrease in this part of the Masurian Lakeland region which encloses the Osa river catchment is within the range of 0–5%. That value is modest when compared to similar changes analyzed in the Gwda River catchment, where they amount to 3.64% (Kubiak-Wójcicka & Lewandowska, 2014). Choiński's studies (2006) revealed that the largest fraction of the lakelands' areas are taken by lakes whose shrinkage trend fits in the 5–10% range. The smallest fraction of the area is taken by lakes with a decrease trend exceeding 10%. Lake basins with a small area or depth are especially threatened with atrophy. Surface area change trends varied in particular lakes. Out of the total number of 267 lakes, 167 increased their area and 100 decreased their area (Figure 6).

Legend: 1 hydrological station, 2 town, 3 river, 4 lakes, 5 watershed.

Lake numbering: 1 Marskie, 2 Klasztorne Pn, 3 Klasztorne Pd, 4 Kucki, 5 8 unnamed, 9 Kołm, 10 Ząbrowskie, 12 Parkun, 13 Osa, 14 Mały Gardzień, 15 Gardzień, 17 Stęgwica, 18 Twaruszek, 19 Szymbarskie, 20 Silm, 21 Mózgowskie, 23 Popówko, 29 Łodygowo, 32 Czarne, 33 Czarne Dolne, 34 Sarnówek, 35 Rybno, 38 Przebernal See, 41 Kraut See, 42 Schloβ See, 48 Środkowe, 49 Gapa, 50 Gubińskie, 53 Plińskie Duże, 55 Kuchnia, 57 Nogat, 58 Szynwałd, 68 Limża, 71 Kisielice, 80 Trupel, 81 Plecnik, 84 Karaś, 87 Kutel, 88 Gil, 92 Księże, 95 Piotrowickie, 100 Dłużek, 102 Papówek, 105 Goryńskie, 113 Święte, 116 Łasińskie, 120 Małe, 130 Szkolne, 137 Piaseczno, 138 Kruszyn, 139 Małe, 140 Salno, 145 Białochowskie, 161 Lisnówko, 162 Szańcowe, 163 Partęczyny, 164 Płowęż, 165 Mierzyńskie, 167 Mierzyn, 173 Wielki Staw, 174 Dębno, 175 Kakaj, 176 Modzel, 179 Przedziene, 180 Moszyska, 181 Lekarckie, 183 Studa, 184 Mełno, 185 Gryfliny, 192 Jajkowe, 199 Kitnowskie, 201 Bobrowo, 202 Szumiłowo, 204 Piętki, 205 Dąbrówka, 222 Duże, 223 Pobocznik, 224 Żaleń, 226 Prątynia, 229 Płociczno, 230 Płociczenko, 232 Kneblowo, 235 Gawłowickie, 236 Gawłowieckie, 238 Blizinki, 242 Gorzechówko, 246 Łopatki, 248 Sicieńskie, 252 Jaśmirek, 253 Wielkie, 254 Praczka, 255 Szenwaldzkie, 258 Wądzyńskie, 260 Głęboczek, 261 Marek, 262 Czarne, 265 Oleczno, 266 Grzywinek, 267 Chojeńskie; the remaining lakes have no names.

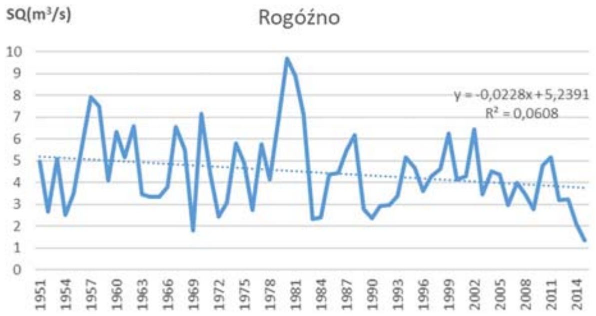

Figure 5. Average annual discharges the Osa river in hydrological station in Rogóźno in 1951–2015 (based on data from the Institute of Meteorology and Water Management – National Research Institute).

4.2.3. *Changes in the area of selected lakes*

The lakes which disappeared completely include those located near the village of Gareja (Figure 7). The examples of such lakes are marked on the Messtischblatt map as 'Groβer See' with an area of 29.47 ha, 'Kraut See' with an area of 12.48 ha and 'Przebernal See' with an area of 12.17 ha. Atrophy of a large water area took place in the case of Schloβ See located near Radzyń Chełmiński, which decreased in area from 50.88 ha to a mere 0.77 ha. The lake Czarne Dolne, in turn, decreased in area from 35.55 ha to 17.84 ha. The main cause of the atrophy or area decrease for those lakes consisted in land reclamation works conducted directly in the area occupied by the lake or in its immediate surroundings, which led to land drying.

The lake Karaś, which is the largest lake in the Osa catchment and decreased in area by approximately 17%, from 449.21 ha to 371.67 ha (Figure 4), is especially worth mentioning. The lake was present on Schroetter's map (1796–1802) and had an area of approximately 646.7 ha. It is exceptionally shallow – its maximum depth is approximately 2.8 m. An inflow of pollutants from agricultural land contributed to excessive overgrowth of the lake in its north-

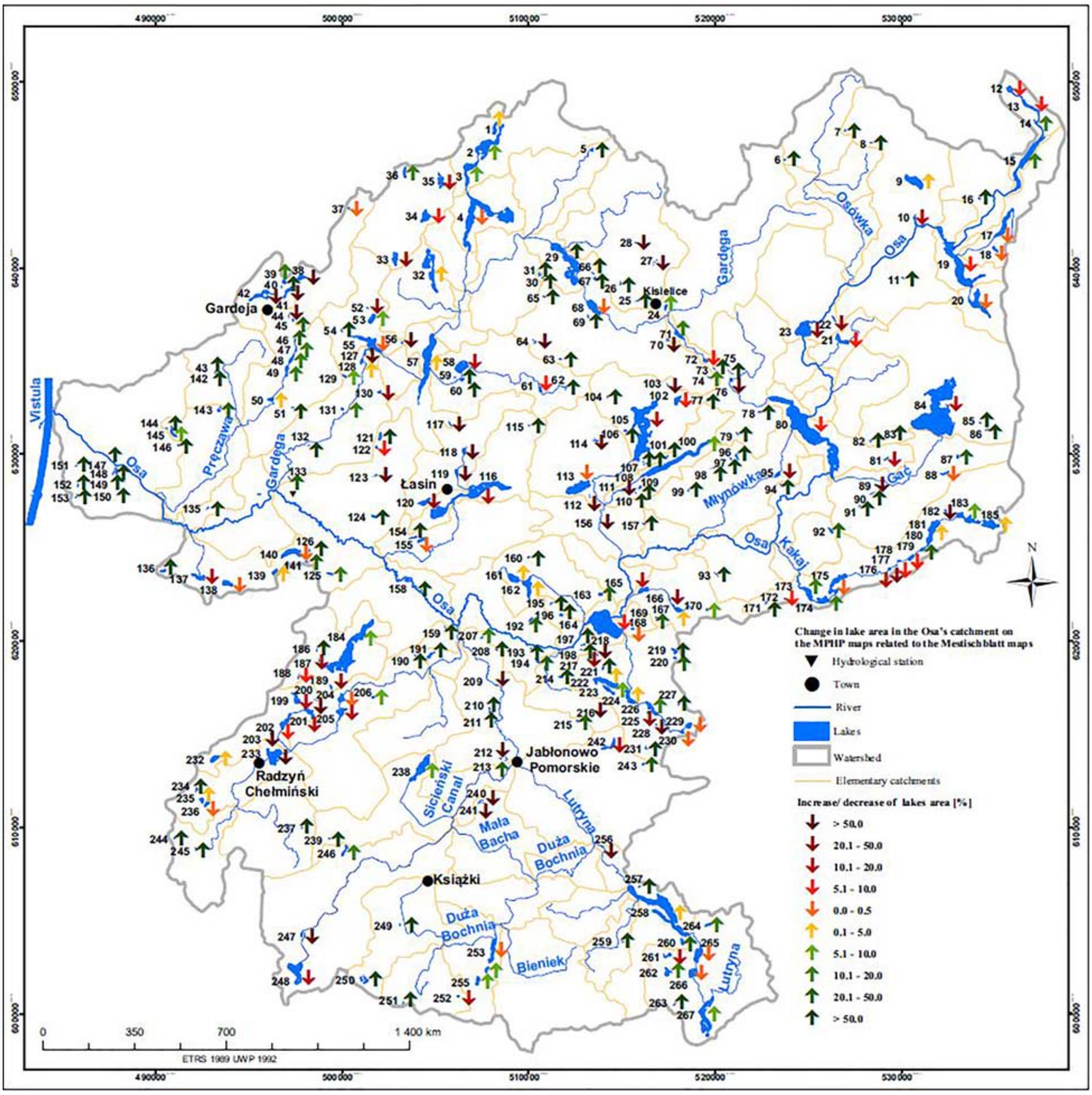

Figure 6. Change in lake area in the Osa catchment on the MPHP maps relative to the Mestischblatt maps.

western part and consequently to the emergence of wetland and a peat bog. Lake area decrease was also noted for lake Kuchnia. Detailed elaboration on that topic is available in the paper by Kubiak-Wójcicka and Golba (2011).

Lake area changes comprise not only decreases but also increases of water surface area (Figure 7). Most often, an area increase is a result of the creation of new reservoirs by damming rivers or by building small artificial reservoirs for economic or agricultural purposes. Lake Łodygowo with an area of 111.17 ha is one of the completely new objects not present on the Messtischblatt maps, but that appeared on the MPHP maps. That lake had existed before, as it was present on Schroetter's map (1796–1802). Then the area of the lake underwent drainage works at the end of the nineteenth century and thus the lake was not present on the Messtischblatt maps. Later on, the area was filled with water again and its outflow is controlled by hydrotechnical structures. Nowadays, the lake is a fish pond. While elaborating on the issue of lake area changes, it is necessary to mention lakes that have not changed their area throughout the last 100 years. An example of such a lake is lake Kakaj with an area of 41.04 ha and a maximum depth of 3.5 m. The direct catchment of that lake consists almost entirely of forests and that is the main reason that its surface area has not altered within that period. Other lakes that changed their area to only a small extent (less than 1%) include: lake Kneblewo with an area of 13.7 ha, lake Kołm with an area of 41 ha, lake Gil with an area of 95.8 ha and lake Nogat with an area of 113 ha.

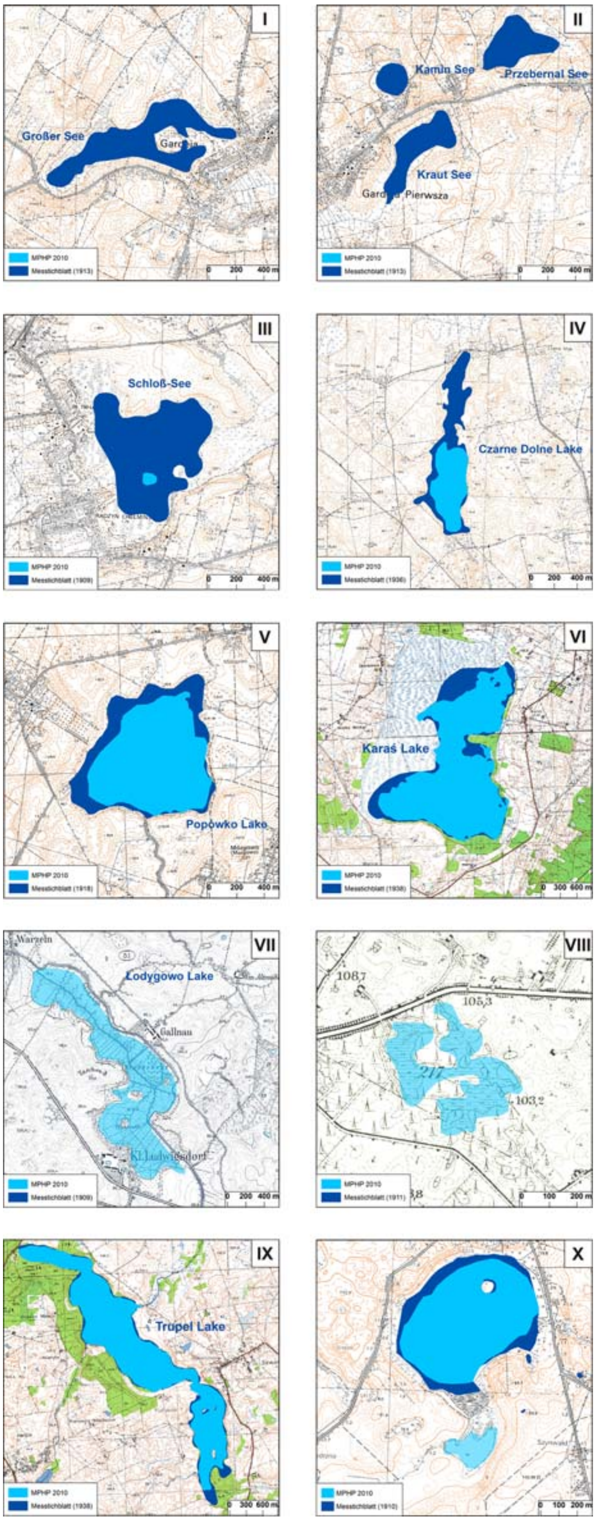

Figure 7. Examples of total lake atrophy Grosser See (I) and Kraut See (II), examples of lake area decrease Schloss See (III), Czarne Dolne Lake (IV), Popówko (V), and Karaś (VI), examples of reconstructed lakes: Łodygowo (VII) and unnamed lake No. 25 (VIII), area changes in lake Trupel (IX) and unnamed lake No. 60 (X).

4.2.4. Trends in lake areas

Table 3 presents a synthetic list of lake area change trends in the Osa River catchment. The changes concern both the decrease and the increase of lake surface area and were aggregated in ranges. It was assumed that the changes in the ranges of 0 to +5% and 0 to –5% may result from measurement inaccuracy and map scales. In the case of 39 lakes, comprising 14.6% of their total number, there was no area change. The largest group comprises lakes whose area increased by over 50% as compared to the German maps – 97 lakes or 36.3% of the total number of analyzed lakes. That increase is a result of the appearance of new water bodies that were not present on the German maps and that are mainly smaller than 5 ha, except for lake Łodygowo, which belongs to the largest lake class in the Osa River catchment. Lakes whose water surface area recorded an increase as compared to previously existing objects comprise just a small fraction of the number. Taking into account total water surface area change, decreases prevailed over increases, which is disadvantageous for the catchment.

Table 3. Lake surface area change trends.

Trend		Number of lakes	% of all lakes	Surface in ha	% of total surface
Area increase	>50%	97	36.3	288.82	31.0
	20–50%	16	6.0	11.30	1.2
	10–20%	19	7.1	28.1	3.0
	5–10%	16	6.0	40.77	4.4
No change	0–5%	19	7.1	23.75	2.6
	−5%–0	20	7.5	−19.03	2.0
Area decrease	5–10%	16	6.0	−63.46	6.8
	10–20%	17	6.4	−176.49	19.0
	20–50%	13	4.9	−62.44	6.7
	>50%	34	12.7	−216.88	23.3
Total		**267**	**100**	**931.04**	**100**

The sum total of the decrease and increase in water surface area of lakes is 888.26 ha, of which 41.5% comprises water surface area increases and 58.5% decreases. Despite hydrotechnical work related to the damming of rivers and lakes, a decrease in area prevails.

An increase in the number of lakes, accompanied by a decrease in total surface area, indicates considerable changes taking place within the catchment. Small water bodies have a small share in the total area of the lakes but a significant share in the total number of the lakes. Those are reservoirs that can be created and then suffer atrophy over a relatively short interval. They are the most vulnerable to any changes in their surroundings: atrophy of large lakes takes more time.

The predominance of total water surface area decline over approximately 100 years matches the data achieved for other regions of Poland (Choiński, 2006). An increase in water surface area results from hydrotechnical work consisting in damming up existing lakes, reconstructing former lakes or building completely new objects. Examples of reconstructed reservoirs can be found in the literature (Kubiak-Wójcicka & Lewandowska, 2014; Ptak, 2017). There is a high probability of further increase in water surface as a result of the construction of small-retention water bodies. A small water retention program was implemented by the State Forests throughout Poland in the years 2007–2013. It included the construction of small reservoirs (up to 10 ha) as well as the damming of lakes. From the year 2016 to 2022, a further program related to small water retention will be implemented. Its aim will be to increase resistance to climate-change-related threats.

The issue of lake area change is not specific only to Poland, but also to many other regions of the world. There are well known examples of large lakes that have disappeared almost entirely as a result of drainage and hydrotechnical works. The largest ones include the Aral Sea (Micklin, 2016), lake Chad (Okpara et al., 2016) and Urmia Lake (Hesami & Amini, 2016). Due to their size and the extent of changes, reverting the lakes to their state from before anthropogenic works is extremely hard and may take a long time. Yang and Lu (2014) point out that in the case of China, the total water surface area has increased but the area of natural lakes has been decreasing, which distorts water relations in many catchments. The changes that have been taking place in the Osa's catchment are not significant when compared to other regions of the world. The largest lakes in the catchment do not exceed 400 ha. The changes were mainly caused by the drainage of lakes and resulted from the need to acquire more arable lands. In certain cases, the reconstruction of a lake is possible. No rapid changes in lake area have been noted as an outcome of over 100 years of works in the Osa's catchment. This may result from various periods of reclamation works. They were conducted in Poland on a large scale in two periods: at the turn of the nineteenth century and in the years 1960–1980. Later on, reclamation works were not conducted on such a large scale. The reconstruction of water surfaces took place as a result of small retention works or the neglect of the irrigation ditch network. Reconstruction of atrophied reservoirs can significantly contribute to increasing water retention or the restoration of biodiversity in the agricultural landscape (Frajer & Fiedor, 2018; Havlíček et al., 2014; Pavelková et al., 2016).

5. Conclusions

The results indicate a general decreasing trend consisting in lake surface area shrinkage in the Osa's catchment. They fit into the trend among lake areas for Polish lake districts under the influence of climate change. Systematic global warming and falling average annual sums of precipitation over recent decades have increased evaporation and reduced the feeding of the basin's water resources. This can be seen in the decreasing discharge of the Osa River. The main reason for the shrinkage of lakes and the large reduction in their area land development consisting in areas occupied by shallow lakes or areas adjacent to lakes being drained. The atrophy and decreasing area of lakes is primarily caused by reclamation works consisting in the drainage of land surrounding lakes or occupied by shallow lakes with a view to obtaining arable land. Apart from decreases in area, increases have also been recorded. However, the share of the latter is smaller. The increase results from hydrotechnical works consisting in the damming of mainly large lakes, as well as the construction or reconstruction of small lakes as a part of a small retention program. Alongside area changes, the largest alterations have taken place in the number of the lakes, especially among lakes smaller than 1 ha. Due to their small area, they are less resistant to changes within their immediate proximity. Knowledge about the changes that have taken place in a lake's area may constitute a basis for public administration, whereby it may set right directions the future use of the lake and the use of the land surrounding it. Once the locations of pre-existing lakes are determined, it may allow the authorities to recreate certain natural lakes as part of planned revitalization of the area. Such actions, leading to restoration to a near-natural state, should constitute the initial stage of renaturalization. The presented archival maps to which Messtischblatts are excellent source material for comparative analyses and are a good tool supporting the work of various specialists.

The problem of lake shrinkage is made extremely complex by the interaction of multiple natural and anthropogenic factors. Attempts to solve the problem of lake shrinkage require further integrated research and the cooperation of many specialists, and have significant consequences for sustainable development and support for decision-making in water resource management.

Softwares

ESRI ArcGIS 10 (with Spatial Analyst Tools). Projected Coordinate System: ETRS_1989_UWPP_1992

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Katarzyna Kubiak-Wójcicka http://orcid.org/0000-0002-9863-3142
Włodzimierz Waldemar Juśkiewicz http://orcid.org/0000-0002-6755-3975

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