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Section: Technologies of Geodesy and Cadastre

Industrial databases for spatial management support

Katarzyna Kocur-Bera, Małgorzata Dudzińska

University of Warmia and Mazury in Olsztyn, Oczapowskiego 2, 10-900 Olsztyn, Poland

Abstract

The management of urban and community space requires decisions and measures that deliver economic and financial stability, guarantee the safe use of public property (including technical infrastructure devices), prevent deterioration of property, support investments and other types of activity. Spatial management should not be regarded as an isolated process, but as an activity that accounts for all aspects of the surrounding space. One of the elements that undergo spatial management are technical infrastructure networks (TIN). The aim of this study is to discuss the applicability of GIS tools and industrial databases for the management of technical infrastructure (water supply system) in emergency situations. A case study was conducted in the town and municipality of Gniew where cartographic analyses were performed to determine the geographic range that could be affected by a failure of the water supply system. The results indicate that industrial databases support effective management of technical infrastructure, facilitate the identification of the most exploited and damage-prone sections of the water supply system and the identification of infrastructure needs. Our findings provide a valuable insight into infrastructure management for local governments and organizations.

Keywords: industrial database; geographic information system (GIS); water supply.

Nomenclature

%	percent
km^2	surface area
m^3	water consumptions – volume of water
m^3/day	water consumptions per day
PLN	currency in Poland (1 EURO = 4.20 PLN)

1. Introduction

Spatial management is a complex process that involves various activities (planning, decision-making, organization, human resource management and control) targeting an organization's resources (human, financial, material, information) that are implemented to effectively achieve an organization's goals [1]. Those activities cannot be effectively performed and coordinated without access to the relevant information. In spatial management, such information is provided by the geographic information system (GIS). GIS is an organized database that contains information about objects and phenomena observed below, on and above the surface of the Earth. GIS software supports complex analyses of information relating to those objects and phenomena [2, 3]. GIS tools are used to describe, explain and predict the distribution of geographical phenomena in space [4]. Information from various sources is combined to develop systems supporting decision-making in economic and social processes that are geographically conditioned [5]. The information supplied by industrial databases expands our knowledge of the analyzed processes and contributes to effective spatial management.

Infrastructure is a broad term that entails public goods and services of strategic importance for the economy and the society. It facilitates the transfer of media, people and objects at no charge or for a fee. Infrastructure is operated by public authorities who have the statutory obligation to build the relevant networks and keep them in good working order [6]. Three types of infrastructure can be identified: economic, social and organizational [7]. Economic infrastructure incorporates business infrastructure (services that support production and the sale of manufactured goods) and technical infrastructure (services that satisfy human needs and promote the growth of the national economy). Social infrastructure involves objects and structures that cater to human needs in the area of education, social welfare, health protection, culture and art.

Corresponding author: Katarzyna Kocur-Bera. E-mail address: katarzyna.kocur@uwm.edu.pl
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Organizational infrastructure is the smallest category that covers management systems in municipalities, counties and regions. This paper focuses on technical infrastructure that can be further subdivided into four categories: energy supply (electrical engineering, gas supply, heat supply), water economy (water supply, sewage disposal, remediation activities), transport and communications, and biosphere protection. Technical infrastructure is characterized by the following attributes: (1) it is largely service-oriented, (2) it generates external benefits for end users, (3) it is capital intensive and its elements are indivisible, (4) its elements are designed for long-term operation and are permanently attached to land (spatial immobility), (5) it cannot be fully operated based on free market mechanisms and requires a certain degree of public management, (6) it is characterized by substitutive and complementary relationships, (7) it facilitates economies of scale, (8) it is burdened with high investment risk [6]. Infrastructure management is a difficult process that has to reconcile the opposing interests and expectations of network owners and end users.

Water is a unique natural asset that affects the health, hygiene standards and welfare of communities [8]. Many regions of the world are affected by water shortages, therefore, the goal of effective management is to guarantee uninterrupted water supply. The management of municipal water supply systems is a complex decision-making process that is based on knowledge and experience acquired during the processing of data relating to water supply networks [9]. Water supply systems are of strategic importance because they incorporate functionally interconnected objects that are critical for national security and guarantee the effective operation of public authorities, institutions and businesses [10]. A typical water supply system comprises: a water collection point, the first pumping station that transports water to the treatment plant, the water treatment plant, a reservoir of treated water, the second pumping station that transports water to the distribution system, equalization tanks, water distribution pipelines [11] and the relevant devices [12]. Computerized decision-support systems are increasingly often used to manage water supply networks. Various commercial applications are available for performing hydraulic calculations of water distribution systems (Wodociągowiec-CAD Gamrat 4.0, KSYDYW, ISYDYW, SYMWOD) or controlling quality parameters (Maike Urban, AQUIS, EPANET) [13], but none of the existing solutions rely on GIS data. GIS software can be applied in four areas of water network management: asset management, distribution management, customer management and outage management. The above sectors can be integrated to improve managerial decision-making. GIS is further applied in the entire lifespan of water supply systems, from planning to implementation, operation and maintenance to replacement [14]. GIS offers asset inventory solutions (keeping records of pipes, valves, fittings, hydrants and meters, including their characteristics and status), it enables operators to identify and prioritize repair and replacement works and close valves to redirect water flow. GIS solutions contribute to service continuity by limiting repair and maintenance time through spatial scenario modeling, identifying areas affected by specific problems and communicating the relevant information to the affected parties. GIS tools are used to establish the direction of flows, localize upstream and downstream points and optimize water pressure to identify isolated sections of a network [12].

The aim of this study was to discuss the applicability of GIS tools and industrial databases for managing technical infrastructure (water supply system) in emergency situations. A case study was conducted in the town and municipality of Gniew where cartographic analyses were performed to determine the geographic range that could be affected by a failure of the water supply system.

2. Materials and Methods

The applicability of industrial databases for technical infrastructure (water supply system) management was evaluated in a series of logical steps including an analysis of water demand (consumption), identification of consumer groups, an analysis of supply network outages and the throughput of water collection points. The above parameters were evaluated with the use of GIS data from the INSPIRE website (geoportal.gov.pl) as well as manuscripts and data sheets from an industrial database. The results were visualized in AUTOCAD software.

3. Case Study

The town and municipality of Gniew are situated in the southern part of the Region of Pomorze, west of the Vistula, in Tczew county (Poland). The municipality of Gniew borders the municipalities of Nowe, Smętowo Graniczne, Morzeszczyn and Pelplin. It occupies the area of 194.12 km^2 (of which 6 km^2 is occupied by the town of Gniew) and has a population of 16,038 [15]. In the analyzed municipality, 80% of residents have access to the water supply network, 60% – to the sewerage system, and 40.8% – to the gas supply network. The water supply system covers the entire town and municipality of Gniew. Local consumers are supplied with water by: the municipal and rural distribution network, rural distribution network covering one village, distribution network operated by a neighboring municipality, private water wells and a private distribution network operated by a local company. The town and municipality of Gniew have 11 water collection points in Opalenie, Nicponia, Wielkie Walichnowy, Brody Pomorskie, Kursztyn, Szprudowo, Piaseczno, Gogolewo, Rakowiec, Jeleń and Cierzpice. The local water supply networks are fed by B-class deep wells. Some networks are equipped with water treatment plants and emergency wells. The local water supply system is largely dilapidated and requires modernization and repairs.

4. Analyses

4.1. Water consumption

The town and municipality of Gniew have access to 11 water collection points situated within their administrative boundaries and 2 water collection points in neighboring municipalities of Nowe and Smętowo. One collection point supplies water to the neighboring municipality of Pelplin. Water consumption (m^3) across consumer groups (2012 data) is presented in Tables 1 and 2.

Table 1. Water consumption across consumer groups. Source: own study

	Public utility buildings (m^3)	Retail, services (m^3)	Food processing industry (m^3)	Light industry (m^3)	Agriculture (m^3)	Industry (m^3)	Households (m^3)
Rural areas	6 953	11 345	571	907	918	116	213 492
Gniew (town)	0	14 102	2 619	0	228	22 544	204 038
Total (m^3)	6 953	25 447	6 190	907	1 146	22 660	417 530

Table 2. Per capita water consumption (*m^3*) in local towns and villages. Source: own study

Name of the place	Water consumptions per 1 inhabitant (m^3)
Gniew (town)	35.31
Rakowiec	15.69
Piaseczno	19.96
Jeleń	15.34
Nicponia	27.80
Szprudowo	19.06
Kolonia Ostrowicka	11.57
Opalenie	9.82
Brody Pomorskie	22.97
Pieniążkowo	19.79
Gogolewo	11.21
Ostrowite	5.78
Wielkie i Małe Walichnowy	46.38
Cierzpice	28.10
Kursztyn	22.87

The data shown in Tables 1 and 2 indicates that households are the largest consumers of water, whereas the lowest consumption levels are reported in the light industry. The highest per capita consumption is noted in the town of Gniew and the villages of Wielkie and Małe Walichnowy, Cierzpice and Nicponia.

4.2. Network outage

The technical condition of the water supply network in the town and municipality of Gniew is highly unsatisfactory. The main problems faced by network operators include a shortage of emergency wells, pipeline layout that does not cater to the needs of the water supply system and an excessive number of end users per one water collection point. The main purpose of emergency wells is to minimize the risk of network outage. In the analyzed area, 33% of water collection points are connected to a single emergency well. The existing solution does not guarantee uninterrupted water supply, and network outages affect the functioning of households and other end-user groups. The safety and reliability of water distribution networks is also determined by the applied piping material. The analyzed system is composed of PVC pipes (37%), asbestos and cement pipes (24%), steel pipes (21%) and cast iron pipes (18%). The evaluated pipelines are old, and they significantly increase the frequency of network outages. Network repair costs in 2010, 2011 and a part of 2012 were compared, and the results are presented in Table 3. The costs associated with sewer line repairs in the corresponding years are also stated for comparative purposes. In the analyzed period, the costs of repairing the water supply system exceeded sewerage repair costs twenty-fold.

Table 3. Water supply system and sewerage network outages (repair costs, number of outages, water supply pipelines, water supply points, water treatment plant, sewerage network). Source: own study

	Number of outages (2010)	Cost of repair (*PLN*)	Number of outages (2011)	Cost of repair (*PLN*)	Number of outages (2012)	Cost of repair (*PLN*)
water distribution pipelines	19	49 696	13	64 558	8	26 189
water distribution connection	16	22 660	10	13 419	2	2 210
water treatment plant (SUW)	5	17 519	1	1 967	0	0
Total (*PLN*)	40	90 147	24	79 945	10	28 398
sewerage network outages	3	8 746	1	1 785	0	0

Frequent outages of the water supply system and long repair times lead to growing levels of consumer dissatisfaction. Pipeline failures should be repaired fairly quickly, and the entire network should be divided into high-priority (e.g. distribution mains) and low-priority (e.g. household connection points) sections. Repair times are influenced by technical aspects (condition of the network, location and type of damage) as well as human resources (size of repair crews, observance of professional standards, work organization) [16]. In line with the engineering standards in the town and municipality of Gniew, failures of the water supply network should be repaired within 2 hours. The network operator is unable to observe the above requirements in practice due to the above constraints.

In the analyzed water distribution system, a single water collection point supplies an excessive number of end users (even several villages). The number of end users and the throughput of every collection point are presented in Table 4.

Table 4. The number of end users and the throughput of water collection points. Source: own study

Water collection point	Number of end users supplied by the network	Supplied villages	Average daily throughput in m^3
Gniew	7 207	Miasto Gniew, Gniewskie Młyny, Ciepłe	767.8
Gogolewo	326	Gogolewo	25.5
Brody Pomorskie	232	Brody Pomorskie	22.1
Szprudowo	325	Szprudowo	39.6
Jeleń	1 670	Jeleń, Rakowiec, Piaseczno, Piaseckie Pola	145.9
Nicponia	1 271	Nicponia, Tymawa	186.3
Opalenie	1 292	Opalenie, Jaźwiska	128.1
Kursztyn	473	Kursztyn	37.8
Cierzpice	118	Cierzpice	19.2
Wielkie Walichnowy	1 697	Wielkie Walichnowy, Kotło, Polskie Gronowo, Kuchnia, Małe Walichnowy, Międzyłęż	250.0
Kolonia Ostrowicka	366	Kolonia Ostrowicka	16.7
Ostrowite	159	Ostrowite	2.8
Pieniążkowo	398	Pieniążkowo, Włosienica, Półwieś	38.7

The above poses a particular problem in Gniew, Wielkie Walichnowy and Jeleń that are connected to a radially distributed pipeline. The failure of a single pipeline branch cuts off water supply to all three destinations. The results of our analysis were presented in maps / thematic diagrams to illustrate the severity of problems in the evaluated water supply system: network outages resulting from failure of different pipeline sections in the town of Gniew (Fig. 1), network outages (Fig. 3) and water consumption across industrial segments (Fig. 4). The town and municipality of Gniew rely solely on analogue maps for network management.

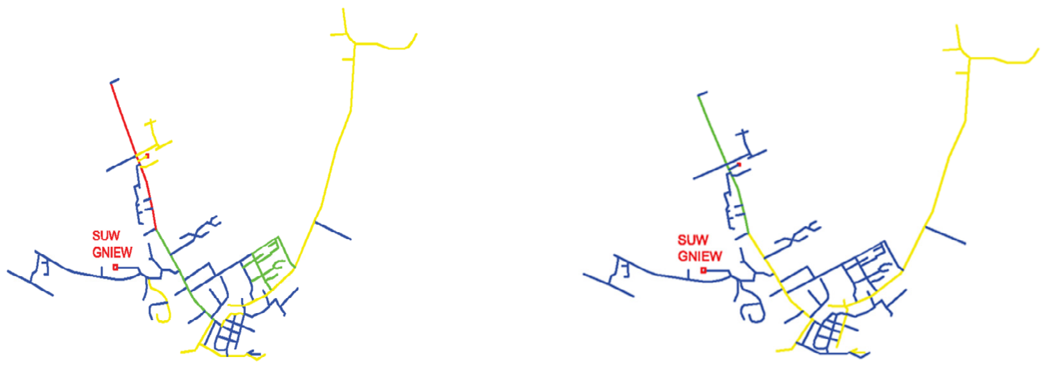

Fig. 1. Network outages resulting from failure of different pipeline sections in the town of Gniew (yellow – up to 2 outages per year, green – up to 4 outages per year, red – more than 5 outages per year) (left figure – 2010 and right figure – 2011 year). Source: own elaboration

The implementation of GIS applications for precise identification of network elements (length, depth, location, piping material) and the use of industrial data (pressure and flow in selected measurement points) support the use of computational models and the determination of changes in water consumption levels, areas characterized by growing water demand and network expansion possibilities (for housing and industrial purposes). GIS tools, industrial databases, monitoring data and computational models can be used to control the network and minimize the number of system outages. GIS and industrial data can be combined to develop an integrated IT system that supports comprehensive system management based on present and historical data and facilitates planning, design and control operations. The main components of a water supply management system developed with the use of GIS tools and industrial databases are presented in Fig. 2.

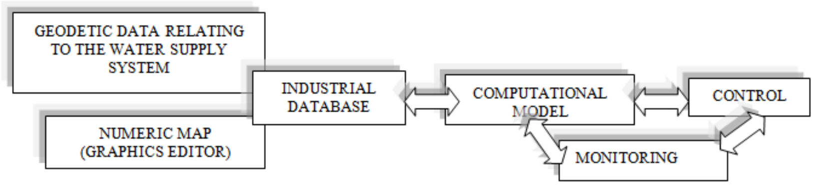

Fig. 2. Water supply management system developed with the use of GIS tools and industrial databases. Source: own elaboration

Emergency and crisis situations involve sudden and unpredictable events, and the resulting network outages generally affect large areas. The priority task in emergency management is to maintain the operability of network sections that supply water to objects of strategic importance and guarantee effective operation of public administration units, institutions and businesses. Detailed information about strategic objects and industrial data should be combined to effectively supply water (or under extraordinary circumstances, to redirect water flows) to selected destinations.

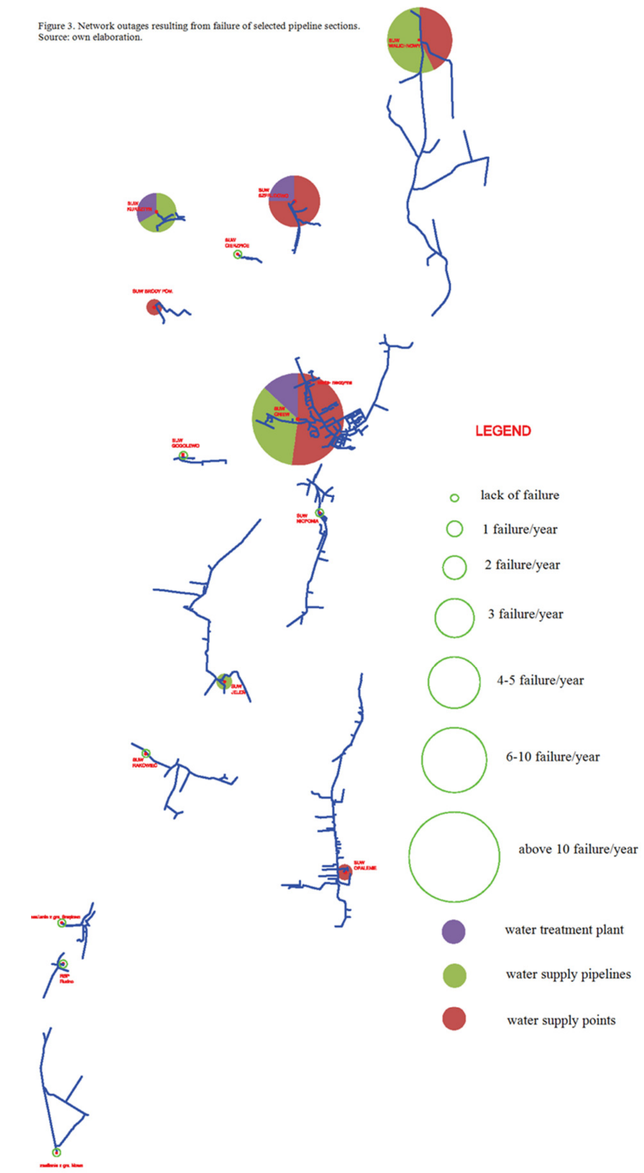

Fig. 3. Network outages resulting from failure of selected pipeline sections

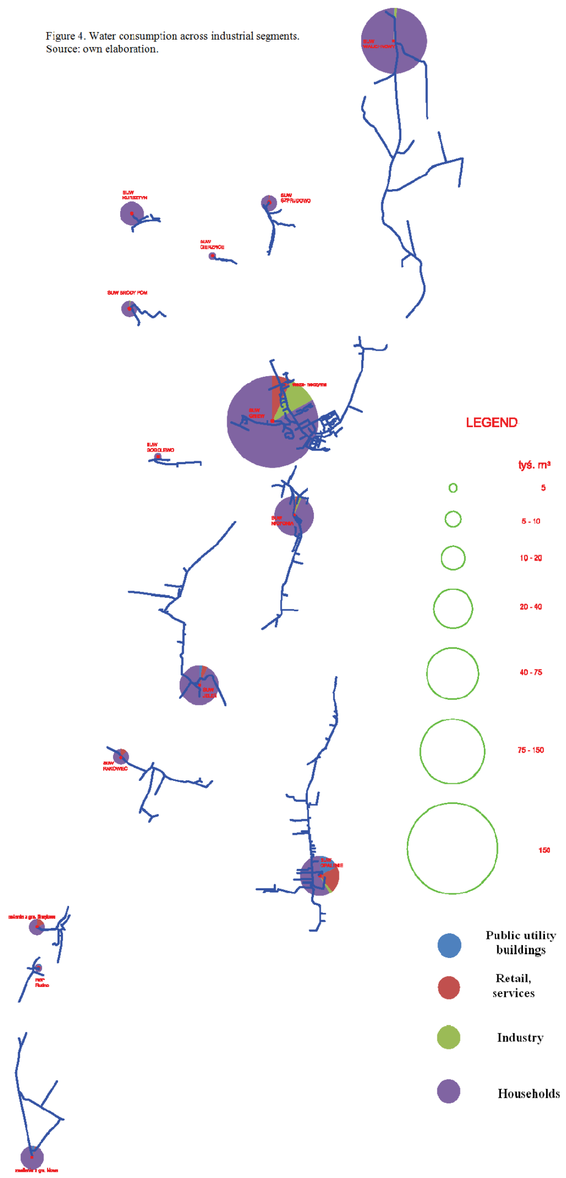

Fig. 4. Water consumption across industrial segments

5. Conclusions

This paper analyzed the applicability of GIS tools and industrial databases for managing technical infrastructure – a water supply system. GIS tools support fast identification of spatial objects, and they can be combined with information from industrial databases to facilitate decision-making and plan solutions relating to water supply management. A case study of the town and municipality of Gniew (Poland) revealed that the analyzed water supply system is largely outdated and that its structure does not support the present level of water demand, which contributes to a growing number of network outages. The use of GIS tools can shorten failure response times and support decision-making relating to network expansion and modernization.

The results of this study provide valuable information that can be used by local governments and organizations to optimize water supply management solutions.

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