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Assessment of the risk of potable water supply in the area of amphibious military operation

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Summary

This paper proposes a method and a "tool" for the assessment and management of the risk of potable water supply in the amphibious military operation area through examples from military history. Amphibious landing is one of the riskiest types of military operations, and the supply of military units with potable water in such operations represents a critical logistic function that may depend on the success or failure of a military operation. Potable water supply is a very important segment in the overall supply, that is the resources without which a soldier cannot endure long-term combat, for there are many examples in military history like this, such as the Battle of Hattin in 1187. The assessment and management of drinking water risk is an area of interest for military logistics and military geosciences. The water supply risk assessment matrix is a "tool" that can help military planners to realistically assess the risk, to determine the level of risk management and a method through which to control this risk.

Keywords:

military geography, military geology, military logistic, risk management, water supply intelligence, military history

1. Introduction

Potable water supply observed through the weight and volume of loads is a major item and heavily burdens the logistic supply chain if water as a resource is not available on the battlefield (**Zečević et al., 2017**). The history of the importance of drinking water supply in military operations can be analyzed through a series of battles in human history from the Middle Ages to the present day (**Moore, 2011; Mather & Rose, 2012**). This has come to be particularly pronounced in amphibious operations. Potable water supply in amphibious operations presents a risk. An example of an amphibious military operation in which the risk of drinking water supply was not identified and analyzed by the planner of the military operation, is the "Gallipoli Campaign" in World War I. Most wells in the range of British and French military units were on the edge of the Gallipoli peninsula, near the beaches. Through increased extraction, these wells were exposed to the penetration of salt water (salt water intrusion), due to the lowering and spreading cone depression, and thus the lowering of the level of the water table (**Zečević et al., 2017**). Lack of drinking water caused many infectious diseases (especially dysentery) during the "Gallipoli Campaign" and reflected on combat readiness, as it increased combat stress. The most common contagious disease was dysentery, which spread rapidly due to poor hygienic conditions, summer heat, and numerous bodies of dead soldiers, piled between the British and Turkish trenches (**Zečević et al., 2017**). In the Gallipoli campaign, British "troops of the 1st Australian Division sometimes operated at an extreme of as little as 1.5 liters of potable water per day per soldier" in the battlefield (**Mather & Rose, 2012**).

Geology of the battlefield can be one of the key factors for the success or failure of a military operation (**Zečević, 2016**). There are numerous examples that insufficient knowledge of geographical features of a battlespace led to the failure of military operation or campaigns. The importance of the influence of geomorphology and geology (including hydrogeology) of the battlefields in the planning and implementation of the amphibious landing is mainly determined by: the nature of the military operation, the area of the battlespace foreseen for the release, the number of soldiers and equipment involved in the operation, the climate in the operations, meteorological conditions, the quantity and quality of the roads, ports and water infrastructure. As the terrain is more indiscriminate and physically demanding, the number of soldiers and equipment is higher, the climate is unfavorable, the water supply infrastructure in an area is of poor quality and quantity, the importance and spectrum of influence of geology and geomorphology on the outcome of the amphibious operation is larger (**Zečević et al., 2017**). Estimating and quantifying the impact of land on the course and the outcome of the

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military operation belongs to the area of military geoscience. "Military Geosciences" is a term which can be useful for encompassing complex geoscientific activities relevant to the military (**Häusler, 2009**). Military actions take place not only on the surface but also below, developing a secure water supply for troops (**Häusler, 2015**). The effect on an army when it comes to a field where there is not enough water can be visualized in an illustrative example of military history, the Battle of Hattin in 1187. The Battle of Hattin, also known as the Battle of the Horns of Hattin, is a medieval battle where Crusaders' forces from Jerusalem became trapped in a waterless desert area without water supply, and thus became easy spoil for the Muslim forces under the command of Saladin (Salah-ud-din) (**David, 1993**).

Water supply risk in an amphibious landing area increases over time, if the number of soldiers is increased in a beachhead area, and it has not been extended to a sufficiently large operational base for sustained military operations. This operational base, among other features, should have sufficient water supply infrastructure or natural springs of drinking water whose yield can supply newcomers with sufficient quantities of drinking water. An example when the number of soldiers increased in a beachhead area, while at the same time there was insufficient water supply infrastructure and natural springs of drinking water, is the amphibious landing on the Gallipoli Peninsula in World War I.

The three core elements of risk management in the logistic supply chain are: 1. Identify the risk to the supply chain, 2. Analyze the risks and 3. Design appropriate responses to the risk (**Waters, 2009**).

The risk can be external and internal. For internal risk, the process owner has an impact on the risk. In this case, the owner of the process is the commander of the military operation, and the process that is analyzed is the process of supplying potable water in the area of operation in which the amphibious landing is being carried out. In case of external risk, the owner of the process has no influence on this type of risk. In this case, an external risk is the influence of enemy forces on the process of the drinking water supply in the area of amphibious landing operation. In this paper, the internal risk type will be analyzed.

2. Risk assessment

The risk can be defined as the possibility of the occurrence of an event that will have consequences for the achievement of the goal. In this paper, the possibility of the lack of potable water for supplying soldiers who undertake amphibious landing is analyzed. Lack of potable water is a risk that could stall and aggravate a military operation. A very clear example of amphibious landing in military history where the lack of potable water was one of the factors influencing the decision to end the military operation, was the Battle of Gallipoli in 1915. An example of a planned amphibious military operation where the risk of water supply was identified, analyzed and appropriate responses to risk was designed was Operation "Sea Lion" in World War II. The German armed forces' invasion of Southern England was planned for September 1940 (**Rose & Willig 2002, 2004a, b**). About 138 000 German troops would land in the first phase of the amphibious landing, but over a period of two weeks, these numbers would increase to a total of about 300 000 soldiers and 30 000 horses (**Willig & Häusler, 2012**). Geologists involved with the 16th Army generated water supply maps at a scale of 1 : 50 000 and each map comprised a topographic base map annotated in black ink to show water supply data (**Willig & Häusler, 2012**). Hydrogeological military geology advice was essential, but it was never put to operational test because Operation "Sea Lion" was ultimately cancelled.

Risk management involves understanding, identification, analysis, quantification and evaluation of the risks. The purpose of risk management is the prevention of adverse events and to control potential risks in advance. The most demanding part of the risk management process is the process of assessing or analyzing the risk of water supply. This part is time-consuming, the most sensitive and at the same time the most important, especially if the quantity, quality and reliability of geographical (hydrological) and geological (hydrogeological) data on the land where the amphibious military operation will be executed, is minor. In this paper, the risk assessment matrix analyzes the battles from military history where the effect that land impacts on the supply of units in a beachhead area is known. However, for the preparation of future amphibious military operations, it is necessary to have an analytical background such as the Heringen Collection (World War II geology and geography military collection which included groundwater prospect information) and experienced military geologists and geographers, who can analyze the beachhead area. The Heringen Collection comprises the libraries and archives of the raw materials division of the German National Geological Service, the Service created by a merger of the former German regional geological surveys, the Military Geology Staff of the Army High Command Inspectorate of Fortifications, which developed in the early years of World War II (**Willig & Häusler, 2012**).

2.1. Risk assessment of potable water supply in amphibious military operation in Guam

Guam is an island (see **Fig. 1**) and territory of the United States in the Pacific Ocean, and a part of the Mariana Islands. It is the largest of the Mariana Islands, with an area of approximately 550 square kilometers (220 square miles). Guam was the site of two amphibious military operations during the Pacific War in World War II. The first amphibious military operation (the First Battle of Guam) took place from December 8th to December 10th, 1941 in Guam. The small American garrison was

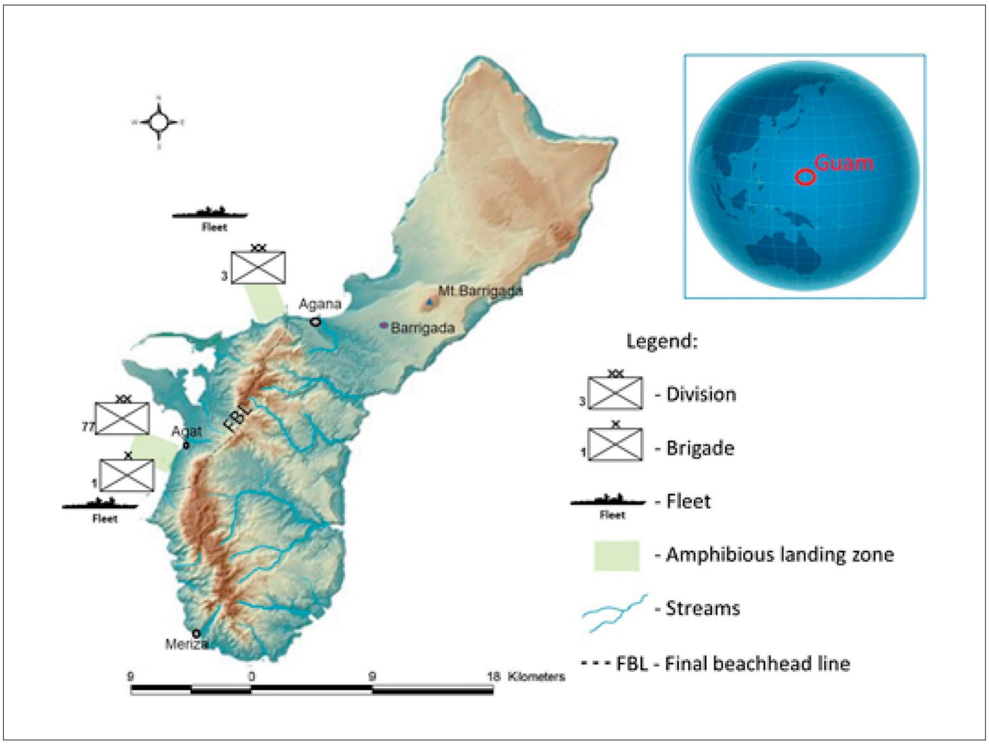

Figure 1: Military operation area with streams and important settlements

defeated by the Imperial Japanese Army on December 10th, 1941. The second amphibious military operation (the Second Battle of Guam) was the American recapture (July 21st – August 10th, 1944) of the Japanese-held island of Guam (**Nelson, 1990**). The seizure of Guam in 1944 added another base to the campaign, whose ultimate goal was to get closer to Japan and defeat the Imperial Japanese Army in Japan.

Much of the Guam coastline is edged with coral reefs and cliffs, and thus presents restricted beachheads, not only for amphibious landing and maneuver, but also for requirements regarding supply and resupply. The northern part of Guam is a permeable karst area without streams (see **Fig. 1**). The southern half of Guam is composed largely of low permeability volcanic rock and all streams in Guam are in the southern half of the island (see **Fig. 1,2**). Most of the streams in southern Guam are small, and the flow has wide seasonal fluctuations (**Ward & Brookhart, 1962**). Guam is warm and humid with an average temperature of 24° C in the coolest months (January, February) and 31° C in the warmest ones (June, July).

Guam island was the object of military geological assessment of drinking water supply before, during and after World War II. The first documented study of the water resources of Guam was by H. T. Stearns, who was making a study for the U. S. Navy in 1937 and describes the general geology of the island, including information on wells, springs, and streams (**Ward & Brookhart, 1962**). The availability of potable water as a resource was one of the key supply requirements for sustainability of the Guam garrison, with regard to the large distance from the supply ports of the U.S. Pacific Fleet. The United States Geological Survey and U.S. Army prepared a technical report in 1962, titled "Military Geology of Guam, Mariana Islands, Water Resources Supplement". This technical report deals with the occurrence and availability of water and the development of water supplies in Guam. The study outlines the water-bearing properties of the rocks, the occurrence of ground water, methods of developing ground water, and it presents records of wells and springs (**Ward & Brookhart, 1962**).

The major ground-water supply in Guam is in the basal ground-water body in the highly permeable limestone (**Fig. 2,3**) in northern Guam (**Ward & Brookhart, 1962**). Due to the high permeability of the limestone, no perennial streams exist on the plateau. Permeable karst limestone quickly absorbs the rainfall and water soon disappears into numerous caverns, sinkholes and fissures (**Ward & Brookhart, 1962; Taboroši et al., 2005**). The largest-volume limestone unit of the northern plateau is the detrital Miocene-Pliocene Barrigada Limestone, Pliocene-Pleistocene Mariana Limestone reef and lagoonal deposit in the northern plateau, however Miocene-Pliocene Barrigada Limestone is the principal aquifer of the northern plateau (see **Fig. 2, 3**), containing the recent fresh-water lens and extending well (**Taboroši et al., 2005**). Depths to the water table (see **Fig. 3**), which is near sea level, ranging from a few feet in the lowlands near the shore to nearly 180 meters (600 feet) in the high part of the limestone plateau of northern Guam (**Ward & Brookhart, 1962**).

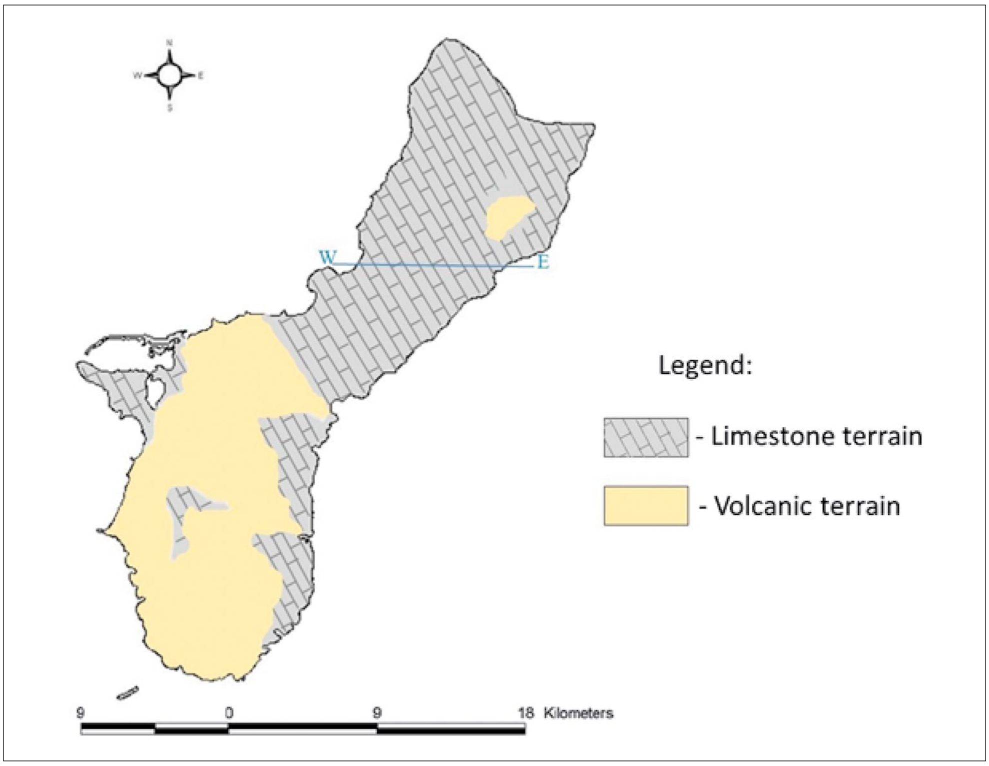

Figure 2: Simplified geological (lithological) map of Guam island (Modified after **Taboroši et al., 2005**)

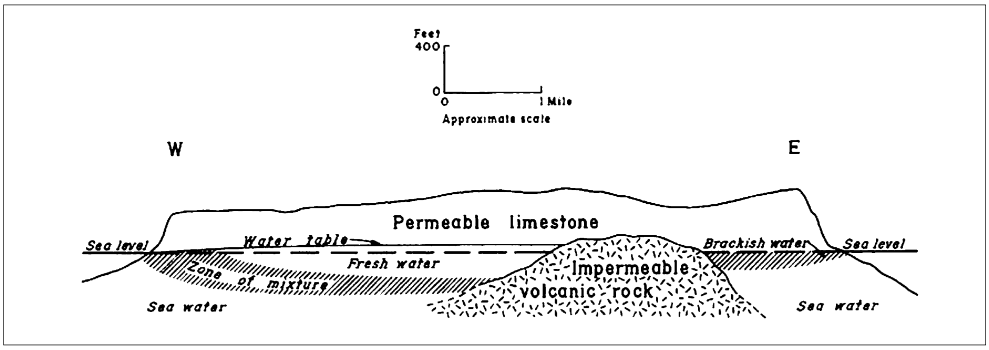

Figure 3: Schematic section (geological profile W - E) showing occurrence of basal ground water in northern Guam (**Ward & Brookhart, 1962**).

The southern half of Guam is composed largely of low permeability volcanic rock and all streams in Guam are on the southern half of the island. Most of the streams in southern Guam are small, and the flow has wide seasonal fluctuations with the greatest flow during the rainy season, from July through November (**Ward & Brookhart, 1962**). Karst on Guam is found in two distinct physiographic provinces. The northern half of the island is an uplifted karst plateau formed on Pliocene-Pleistocene reef-lagoon deposits. In the south, the karst is mostly confined to Miocene remnants on uplifted weathered volcanic terrain (**Taboroši et al., 2005**). The southern half of the island, which is largely composed of volcanic rock with low permeability, and several villages in southern Guam divert small water supplies from streams (**Ward & Brookhart, 1962**).

The 3rd Marine Division landed near Agana, while the 1st Provisional Marine Brigade and 77th Division landed near Agat. As the troops of the 1st Provisional Marine Brigade pushed inland, they came under more fire from mortars and artillery (**Nelson, 1990**). The Japanese Imperial Army tried to stop the landing with a counterattack. Given that they could not stop the landing, they tried to disable the merging of the U.S. forces. On July 28th, 1944, the two beachheads were linked (Final beachhead line) and secured (see **Fig. 1**). After unique and sustainable beachheads were established, water was carried on transports at a level of two gallons (7.5 liters) per man per day, making a total of 190 000 gallons (approximately 720 000 liters) and 77th Division carried water in 5-gallon and 55-gallon drums (**Nelson, 1990**). That amount of potable water was sufficient for the division's needs for a maximum of twenty days. These quantities would be sufficient for the provisional sustainability of the landing U.S. Forces. Due to the critical small amounts of drinking water in the area of the beachhead, an insufficient quantity for long-term sustainability of U.S. Forces on the island, in the context of supplying sufficient quantities of drinking water, it was necessary to occupy the village of Barrigada (see **Fig. 1**), which had a huge reservoir capable of pumping 75 700 liters (20 000 gallons) of water a day. The Commander of military operation identified the risk in the planning of the operation, assessed its significance, and in response to the level of risk, directed the 77th Division (with the support of the 3rd Marine Division on the left wing of the attack) to take Barrigada Village as soon as possible, thus ensuring long-term sustainability of the U.S. Forces in military operation.

Until the time the village was occupied, "the men of the 77th Division had quenched their thirst by getting water from streams and creeks" (**Nelson, 1990**). The reservoir would be the only source of supply, because in the northern part of Guam, there were no streams. Due to this fact, the Imperial Japanese Army concentrated most of the remaining forces around the Barrigada village. The village of Barrigada is located near the center of the island on Guam's limestone plateau and it consisted of only twenty buildings during the Second World War. North of the village, Mt. Barrigada is located (see **Fig. 1**). U.S. Forces faced fierce resistance from the Imperial Japanese Army on August 2nd and 3rd, 1944 in what came to be known as the "Battle of Barrigada." In the battle, both sides used tanks, infantry and artillery in order to conquer, or retain, water resources. With great losses on both sides, the Imperial Japanese Army was pushed out of the village. On August 3rd, the 3rd Marine Division reached the top of the Barrigada Mount by midafternoon, and thus ensuring the supply of drinking water. The next day, the advance continued and the Japanese Forces were pushed to the north of the karst part of the island, which had no surface currents and significant sources of drinking water and they did not have the capability of supplying themselves with fresh water from the deep aquifer (engineering units and equipment were required to establish adequate water supplies for groundwater exploitation).

The U.S. Navy had prevented the sea and air supply of Japanese Forces in Guam. In the next ten days, the rest of the Imperial Japanese Army surrendered or was destroyed. Thus, Barrigada village with its reservoir and pump station has, in military terminology, the significance of a *decisive point*. Decisive points are usually geographic areas, sources of military power whose conquest or destruction, surveillance or defense provides a significant advantage for the realization of a military operation. One of the most respected military thinkers of their time, general Antoine Henri de Jomini (**1838**) in his theoretical writings (Art of war, "*Precis de l'Art de la Guerre*") states that the decisive point of a battlefield "will be determined by: 1. The features of the ground, 2. The relation of the local features to the ultimate strategic aim, and 3. The positions occupied by the respective forces." The occupation of Barrigada Village created the operational base for the U.S. Army and the long-term sustainability of the units in the context of drinking water supply. At the same time, the Imperial Japanese Army was deprived of the ability of supply with drinking water.

3. Access, risk assessment methodology and quantification of potable water supply risk

In this paper, the risk is assessed on the basis of a qualitative approach. A qualitative approach to risk assessment qualitatively evaluates the values of individual parameters and their impact on the risk being considered. When using such an approach, experience and expertise of risk assessment experts are of great significance in order to diminish the subjectivity of judgment. In a qualitative risk assessment, the parameters are quantified, but the obtained numerical values are not absolute, but relative. The risk assessment matrix has a broad application in economics and management (**Dumbravă & Iacob, 2013**), and there is no reason why it should not be used in military logistics when assessing the water supply risk in the area of amphibious military operation.

3.1. Risk assessment matrix

Risk assessment consists of risk influence and risk probability estimates. Risk assessment can be quantified through a risk matrix; each of two variables is one axis of the risk matrix (see **Fig. 4**). The impact (risk influence) of drinking water supply risk depends directly on the number of soldiers in the area of operation (number of soldiers who need to be supplied with drinking water every day). The risk probability directly depends on the factors of the land (geospatial factors). Geospatial factors that depend on drinking water supply in the beachhead area can be divided into four groups. These factors are related to the distribution, quantity and quality of water infrastructure in the beachhead area, surface water related factors, groundwater factors, and factors related to climate and weather conditions (expected temperatures in the area of operation). The risk assessment matrix allows risk to be quantified in categories 1 through 7 (see **Fig. 4**).

3.2. Impact risk assessment (influence on water supply)

In World War II, the German Army worked on the basis of a potable water ration of 7.5 liters per day for one soldier in the field, which could be reduced to 2.0 liters per day for a limited period under intensive battle

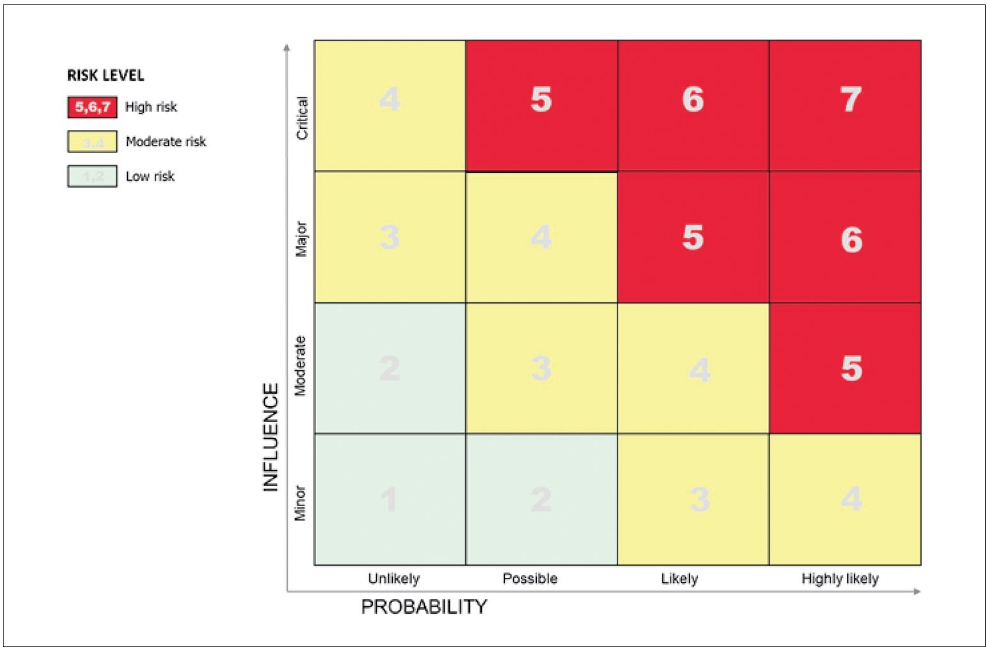

Figure 4: Risk assessment matrix (structure of probability – influence matrix)

conditions (**Willig & Häusler 2012**). For minimum hygienic conditions, it is necessary to provide an additional 6 to 10 liters per day for one soldier in the field. The amount of potable water per soldier also depends on the weather conditions.

The impact of the event increases with a proportional increase in the number of soldiers in the operation. It is significantly easier for logistics to supply one platoon or company than one division. If operations are carried out at distances greater than the main ports, the supply of units at larger distances is a major logistical requirement. In the presented risk assessment table, the risk impact of amphibious military operations is analyzed, involving up to 200 000 soldiers. Amphibious military operations involving more than 200 000 soldiers are very rare and the supply of amphibious military operations of such magnitude represent a high risk for drinking water supply and are a huge logistical challenge. An example of amphibious military operations that represented a huge logistical challenge was the amphibious assault in Normandy, and British geologists had a major role in assessing and managing the potable water supply risk. Approximately 150 000 soldiers landed in Operation Neptune on the first day of the operation to increase the number of soldiers in the area of operations for the next two months to approximately 1 300 000. However, in those two months, the beachhead expanded and an operating base was created that included cities and ports with quality water supply infrastructure. In the first step of the military operation, water in Normandy was largely obtained from rivers and existing wells, supplemented by 33 new boreholes, and water supply intelligence as well as control of well siting and drilling were a military geologist's responsibility (**Rose & Pareyn, 1998**).

3.3. Risk probability estimation used for water availability calculation in military operations

The likelihood of events increases with the proportional characteristics of the unfavorable terrain characteristics and represents the cumulative effect of four factors in the battlespace affecting the supply of drinking water; (1) water supply infrastructure, (2) surface water supply, (3) supply with groundwater, and (4) climate, weather conditions (expected temperatures in the area of the operation). Each of these factors varies from 0 (zero) to 1 (one), and the cumulative value varies from 0 (zero) to 4 (four). When the terrain characteristics are more favourable, the cumulative value is closer to zero, and less favorable terrains have values increased up to the number four (see **Fig. 4**, **Fig. 5**). The assessment is based on map analysis and expert assessment. These four attributes are interrelated and can be seen as entities, but for the needs of the matrix, the risk assessment will be quantified separately (see **Tab.1**).

3.3.1 Assessment of water supply infrastructure

Assessment of water supply infrastructure includes all infrastructure related to water supply, built on some land (water distribution networks, aqueducts, wells). Water supply is facilitated if the troops are moving through populated and developed areas with developed water supply infrastructure. In such cases, existing civilian water utilities can be used.

3.3.2 Estimation of the impact of surface water on supply

Estimation of the impact of surface water on supply includes all watercourses and lakes with potable water in

Table 1 Comparison of Risk Assessment data for Operation “Husky” and Gallipoli Campaign

„Operation Husky” (Sicily, Italy, WW2, 1943)	**Number of soldiers (initial)**				**165000**
	Characteristics of the land (0 - favorably, 1 - adverse)				**1.4**
	Water supply infrastructure	Hydrology	Hydrogeology	Climate/season	
	0.2	0.4	0.2	0.6	
Gallipoli Campaign (Turkey, WW1, 1915)	**Number of soldiers (initial)**				**30000**
	Characteristics of the land (0 - favorably, 1 - adverse)				**2.1**
	Water supply infrastructure	Hydrology	Hydrogeology	Climate/season	
	0.6	0.6	0.3	0.6	

the area of operation that can serve as a supply. The possibility of very easy contamination of these resources by military action should be taken into consideration.

3.3.3 Assessment of the impact of groundwater on supply

Assessment of the impact of groundwater on supply includes all potable water reserves in the underground that can be used to supply potable water to the units in the area of the well-being operation or in other ways. In this assessment, it is important whether the owner of the process (the commander of the military operation) has engineering units and equipment required to establish adequate water supplies from groundwater aquifers at his disposal. For example, the British military geologists during operation “Neptune” (World War II) created ‘Normandy’ maps (hydrogeological maps at a scale of 1 : 50 000) and outlined seven key data sets; (1) the areal extent of the aquifers, (2) depth of the water table (where available), (3) depth to the base of the aquifer (as a guide to optimum drilling depths for each discrete aquifer unit), (4) aquifers ranked (development potential and likely optimum borehole depth) (5) comments on weakly permeable rock units and likely occurrences of useable shallow wells and springs, and surface waters, (6) likely spring lines in areas where drilling might not otherwise be productive, and (7) areas of adverse water quality (including risk of seawater intrusion) (**Robins et al., 2007**).

3.3.4 Assessment of climate, seasonal influences and expected temperature in the beachhead area

In dry, rocky, arid or semi-arid areas and conditions such as in the executed operation “Husky” (Sicily, Southern Italy, World War II, 1943) and the Gallipoli Campaign (Turkey, World War I, 1915), it is much harder to accomplish supply with potable water than for example in Normandy (France, World War II, 1944), in operation “Neptune”. These military operations took place in the summer months, when the temperatures approached 40 degrees Celsius.

For example, Sicily is a semi-arid and rocky large island, and this is mostly related to the southern and south-eastern part of Sicily, which is made of carbonate rocks. In that part of Sicily, a beachhead was established by the American and British forces. Drinking water in the port Syracuse area is critical in the summer months. Since the 8th Army, under the command of General Bernard Montgomery, was landed in this area, it was dependent on a small number of wells and springs of potable water, whose capacity was dependent on seasonal influences (**Nelson & Rose, 2012**).

In the initial stage of the Gallipoli Campaign, the risk of drinking water supply can be estimated as moderate, and for the operation “Husky” as high (see **Fig. 5**).

Operation “Husky” is an example of amphibious military operation in which the risk of drinking water supply was recognized, analyzed and managed. The military operation dynamics enabled a relatively rapid spread of the beachhead and the creation of a favorable operating base for the continuation of the military operation. The Gallipoli Campaign was an amphibious military operation, in which the risk of potable water supply was not timely recognized. As a result, British and French military units had a lack of potable water in the beachhead area. Logistics supply lines were overwhelming and over-loaded with regard to capacity, and supply in the area of operation was insufficient, given the number of soldiers. The planning of drinking water supply showed only one in a row of failures when planning the Gallipoli Campaign (**Zečević et al., 2017**). During the Gallipoli Campaign, supply conditions and land factors significantly deteriorated in the time from initial lending of units in April and May to the subsequent landing in Suvla Bay, in August 1915. Meanwhile, some wells with drinking water were contaminated on the battlefield, and in others, there was a seasonal penetration of salty water in the aquifer, due to recovering (**Zečević et al., 2017**). The number of soldiers had increased rapidly and this further burdened the logistics supply chain (**Tab 2**, **Fig. 6**). The land occupied in the Suva Bay could not significantly increase the supply in the area of operation, and summer temperatures had risen and surface watercourses would have been completely dry.

Water supply risk increases over time (see **Fig. 6**) if units do not expand the beachhead area and create a minimum operating base (*base of operation*) in which it ex-

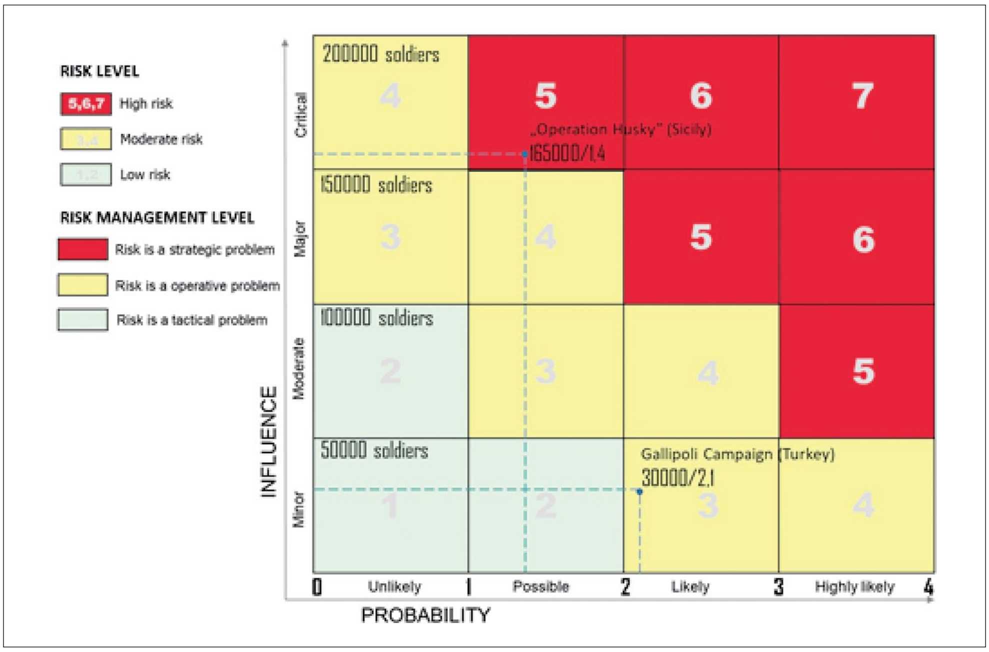

Figure 5: Risk assessment matrix (water supply) and risk management level

Table 2: Comparison of Risk Assessment data for Gallipoli Campaign in the initial stage and finally

Gallipoli Campaign (initial, April - May)	**Number of soldiers**	**5 divisions (initial)**			**30000**
	Characteristics of the land (0 - favorably, 1 - adverse)				**2.1**
	Water supply infrastructure	Hydrology	Hydrogeology	Climate/season	
	0.6	0.6	0.3	0.6	
Gallipoli Campaign (final, August - December)	**Number of soldiers**	**15 divisions (final)**			**170000**
	Characteristics of the land (0 - favorably, 1 - adverse)				**3.1**
	Water supply infrastructure	Hydrology	Hydrogeology	Climate/season	
	0.6	1	0.7	0.8	

ists or it is possible to build supply infrastructure (wells, springs, aqueducts) that can provide a sufficient amount of potable water for units. The Gallipoli Campaign is an example where units, after seven months, did not significantly increase the beachhead area, and created the *base of operation* that had enough water resources in the area of operation to continue the military campaign. Operation "Husky" is an example of an amphibious operation where the beachhead area was expanded rapidly enough and almost the whole of Sicily was occupied in one month. Although the number of soldiers climbed from 165 000 to nearly half a million, the conquest of the entire island (Sicily) created a sufficient operational base for the sustainability of the operation. Operation "Neptune" (D-Day, Normandy) is an example of a well-planned amphibious military operation where the risk of water supply was identified, analyzed and appropriate responses to risk were designed. Immediately after the landing (D + 1), the groundwater began to crumble in the beachhead area. For example, west of the Orne River in the British sector, one water point with a capacity of 91 000 liters per day was open with increasing output in subsequent days (**Rose & Pareyn, 1998**). The water exploitation was then continued at many sites within the beachhead area. In the next two months, the beachhead area expanded, and an operating base was created with a quality water supply infrastructure that allowed for the continuation of the military operation.

4. Discussion and Conclusions

The risk assessment matrix of water supply is simplified and can be included in the Military Decision Making Process (abbr. MDMP) as such. The Military Decision Making Process has seven steps. The water risk assessment matrix might be included in the second step of the military decision-making process (Step 2: Mission Analysis). At Operational Art of War, there are three operational factors - Battlespace, Time and Forces. If we include "Time" as an additional (third) axis in the risk assessment matrix, and then it becomes three-dimensional (see **Fig. 6**).

There are two conditions for applying such a risk matrix that directly affect the reliability of the proposed risk

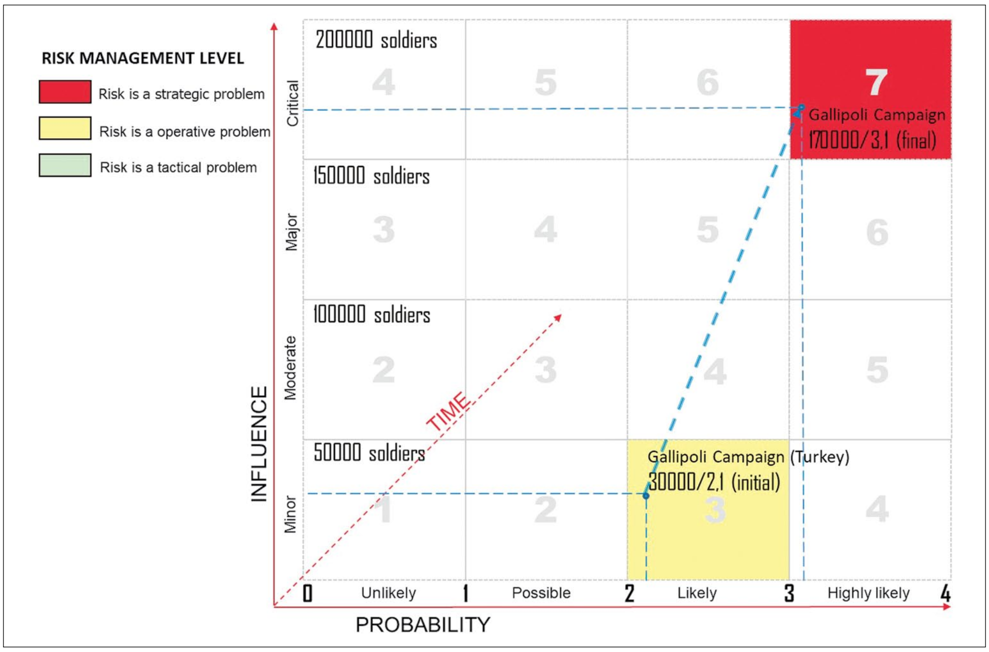

Figure 6: Risk assessment matrix (water supply) and risk management level for Gallipoli Campaign in the initial stage and finally

assessment method. Both conditions must be satisfied so that the commander of the operation and his headquarters accept the risk assessment results as reliable. The first condition is the quality and quantity of input data for risk assessment and the second is the availability of experts (experienced military geologists and geographers) who make estimates based on input data. During World War II., German military geographers and military geologists had access to the Heringen Collection, and today's analysts have additional methods and tools such as remote sensing and GIS (Geographic information system) analytical support for the evaluation of risk. Remote sensing enables the collection of one part of data related to surface waters and surface water supply infrastructure. The GIS is an information system that involves gathering, storing, processing, structuring and updating the digital geospatial data for data analysis and creating various sorted maps, statistics and databases. GIS technology enabled data input in the form of data layers that could be generated from satellite images, aircraft photographs, geological and topographic maps and other data sources necessary for field analysis. GIS provides storage and analysis of data such as hydrological, hydrogeological and geological maps and profiles that are most important for supplying potable water risk assessment.

If the risk assessment shows that the risk of supplying drinking water in the beachhead area is high (category 5, 6 and 7), that is a strategic problem and then the commander of the operation and his headquarters should be managing the risk. The commander of the operation, already in the planning and preparation phase of the operation, in the structure of the forces that will carry out the military operation, should include engineer units (infrastructure engineering) that can repair the destroyed water supply infrastructure or, if there is no such infrastructure in the beachhead area, to make wells for supplying drinking water. It is also necessary to plan for the occupation, security and maintenance of such a critical infrastructure as part of a military operation. The risk management process enables the development of a key land acquisition strategy and the assignment of tasks to logistics and engineering units, in order to increase the supply of potable water to the area of operation. If the water supply risk is moderate (category 3 and 4), then it should be managed by the logistical chief of military operation, and if the risk is small (category 1 and 2), it should be in the hands of lower tactical commanders. Category 7 in the risk assessment matrix represents an extremely high or unacceptable risk. Based on such risk assessment, the commander of military operation may change the site of amphibious landing or cancel the amphibious operation.

In addition to the (internal) risk that can be estimated in the planning process of military operation through the risk matrix, there is also an external risk that is much more difficult to estimate in the planning process. The external risk to the drinking water supply process in an amphibious operation area is the influence of the enemy on the supply chain. The enemy goal is to destroy or at least disrupt the supply for troops in the area of amphibious military operations. Thus, the enemy can act on logistic and engineering units that have the task of carrying out the supply. The overall (internal and external) risk is always higher than the internal risk alone, and the commander of the military operation in case the internal risk is very high or extremely high (categories 6 and 7) could estimate that the overall risk is too high for the implementation of a military operation.

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PROŠIRENI SAŽETAK

Procjena rizika opskrbe pitkom vodom u području pomorskoga desanta

U ovome radu predložena je metoda za procjenu i upravljanje rizikom opskrbe pitkom vodom u području desantne vojne operacije na primjerima iz vojne povijesti. Desantna operacija jedna je od najrizičnijih vrsta vojne operacije, a opskrba vojnih postrojbi u takvoj operaciji predstavlja kritičnu logističku funkciju o kojoj, u znatnoj mjeri, može ovisiti uspjeh ili neuspjeh vojne operacije. Opskrba pitkom vodom predstavlja vrlo važan segment u cjelokupnoj opskrbi. S obzirom na to da je pitka voda resurs bez kojega se ne može, procjena i upravljanje rizikom opskrbe pitke vode zahtjev je koji se postavlja pred planere i zapovjednika vojne operacije. Procjena i upravljanje rizikom pitke vode područje je interesa i vojne logistike i vojnih geoznanosti. Matrica rizika opskrbe pitkom vodom „alat" je koji može pomoći planerima vojne operacije da realno procijene rizik, odrede razinu upravljanja rizikom (taktička/operativna/strateška) i načine upravljanja tim rizikom. Rizik opskrbe pitkom vodom u području desanta povećava se, odnosno raste kroz vrijeme ako se povećavaju desantne snage u području mostobrana, koji nije proširen na dovoljno veliku operativnu osnovicu s koje bi se mogla omogućiti održivost vojne operacije. Takva bi operativna osnovica, uz ostale poželjne karakteristike, trebala imati dovoljnu vodoopskrbnu infrastrukturu ili prirodne izvore pitke vode čija izdašnost može opskrbiti novopristigle snage dovoljnim količinama pitke vode. Primjer za povećavanje vojnih snaga u području mostobrana uz istovremeno nedovoljnu vodoopskrbnu infrastrukturu i prirodne izvore pitke vode jest desantna vojna operacija na Galipolju 1915. godine. Ako procjena rizika pokaže da je rizik opskrbe pitkom vodom u području mostobrana visok, odnosno da je strateški problem, tada takvim rizikom treba upravljati zapovjednik operacije i njegov stožer. Zapovjednik operacije već u fazi planiranja i pripreme operacije treba u strukturi snaga koje će provesti vojnu operaciju uključiti inženjerijske postrojbe (infrastrukturnu inženjeriju) koja može popraviti uništenu vodovodnu infrastrukturu ili ako na prostoru desanta nema takve infrustrukture, izraditi bunare za opskrbu pitkom vodom. Isto tako, u planu vojne operacije treba predvidjeti zauzimanje, osiguranje i zadržavanje takve ključne infrastrukture. Proces upravljanja rizikom omogućava razvoj strategije zauzimanja ključnoga zemljišta i postavljanje zadaća logističkim i inženjerijskim postrojbama u cilju povećane opskrbe pitkom vodom u području operacije. Ako je rizik opskrbe pitkom vodom umjeren, tada bi njime trebao upravljati glavni logistički časnik operacije, a ako je rizik malen, on bi trebao biti u nadležnosti nižih taktičkih zapovjednika. Kategorija 7 u matrici procjene rizika predstavlja iznimno visok ili neprihvatljiv rizik. Na temelju takve procjene rizika, zapovjednik vojne operacije može promijeniti mjesto iskrcavanja pomorskoga desanta ili otkazati desantnu operaciju.

Ključne riječi:
vojna geografija, vojna geologija, vojna logistika, upravljanje rizikom, opskrba vodom, vojna povijest

Author contribution

All contributions (research, writing of the text, preparing of the figures) go to the author Lieutenant Colonel Marko Zečević, Ph.D.