Chapter 8

Geospatial Analysis of Water Resources for Sustainable Agricultural Water Use in Slovenia

Matjaž Glavan, Rozalija Cvejić, Matjaž Tratnik and Marina Pintar

Additional information is available at the end of the chapter

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1. Introduction

Global population growth has greatly increased food demand. This, in turn, has intensified agricultural production, already the biggest consumer of water in the world [1]. Development of irrigation techniques has contributed to the global food production [2]. However, climate change simulations predict repeated droughts and deteriorating crop production, illustrating the critical need for sustainable irrigation [3]. Thus, a proactive water management strategy is a priority of any government in the world.

Globally, only 10% of estimated blue water (surface water, groundwater, and surface runoff) and 30% of estimated green water (evapotranspiration, soil water) resources are used for consumption. Nevertheless, water scarcity is a problem due to high variability of water resources availability in time and space [4]. Model results suggest that severe water scarcity occurs at least one month per year in almost one half of the world river basins [5]. One third of the water volume currently supplied to irrigated areas is supplied by locally stored runoff [6]. It is estimated that small reservoirs construction could increase global cereal production in low-yield regions (i.e. Africa, Asia) by approximately 35% [6]. Global water scarcity problems can now be, due to advances in hydrology science in the last decades, easily assessed on fine temporal and spatial scale [4].

Irrigation development and management in Slovenia have completely stagnated in the last decade due to financial shortages. In 1994 the Slovenian government adopted a strategy for agricultural land irrigation (i.e. National Irrigation Programme) [7]. In 1999, the World Bank prepared a feasibility study of this program. However, economic constraints and lack of political will limited the implementation of the program [8].

Slovenia is experiencing periodic droughts of varying intensities in different parts of the country. According to the Court of Audit, the total costs in the agricultural sector due to the droughts in 2000, 2001, 2003 and 2006 were 247 million euro (EUR) [9]. During the same period the government spent 85.9 million EUR for the elimination of the consequences of droughts, and only 3.3 million € on drought prevention measures. This figure is particularly worrisome, because Slovenia is relatively rich in water, with 800-3,000 mm of precipitation per year. With appropriate technical measures, water could be redistributed temporally and spatially, limiting water scarcity and drought effects. Recurring droughts and the results of global and regional climate scenarios [10] predict a tightening of crop production conditions in Slovenia, illustrating the urgent need to address the availability of water resources [11-17].

The Ministry of Agriculture and the Environment has identified the current lack of irrigation infrastructure as a serious obstacle to prevention of agricultural damage and improvement of crop production. Therefore, the Ministry called for two research projects of the Target Research Program, as preparation for the establishment of a new Irrigation Strategy. The first project, Water Perspectives of Slovenia and the Possibility of Water Use in Agriculture (V4-0487) [9, 18], had two objectives, (a) to determine the current water quantity of Slovenian water resources (ground and surface waters, wastewater and sewage treatment plants discharges, existing large reservoirs) potentially available for use, with emphasis on irrigation and (b) to determine the extent to which these water resource meet current irrigation needs.

In 2012 the second project, Projections of Water Quantities for Irrigation in Slovenia (V4-1066) was completed, with the objective to determine to what extent the surface runoff water retained in small water reservoirs along with the rest of the available water, from other water resources, covers irrigation needs. The project also took into account the irrigation norms for different crops, soils, climate zones and climate change scenarios [19]. Analyses of the available water quantities, potential irrigation areas, technical possibilities of construction of small reservoirs, legislation, irrigation norms for crops, climate change impacts were made as part of the agricultural drought risk assessment.

The purpose of this chapter is to present a novel and globally applicable approach for identification of agricultural lands that are at risk for drought. Spatial analysis of available water resources and their quantities for the sustainable irrigation of agricultural land is the key to an efficient integrated water management strategy. Knowing the spatial distribution, accessibility, abundance and availability of water resources is an important element of national security, with regards to the production of sufficient quantities of quality food. Assessing water resources is especially critical in the light of empirical meteorological data and climate model results showing clear changes in the allocation of precipitation and in seasonal patterns.

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Water resource	Data type	Description/properties	Data source
Surface watercourse	River network	Polyline layer	Slovenian Environmental Agency (SEA)
	River flow	Geo-referenced tabular data - river flow gauging stations ($m^3 s^{-1}$)	
	Water abstraction	Geo-referenced tabular data	
	Available water quantities	Geo-referenced tabular data - water available for irrigation and ecologically acceptable flow ($m^3 s^{-1}$)	Institute of Water of the Republic of Slovenia (IWRS)
Large water reservoirs	Reservoirs	Polygon layer	IWRS
	Reservoir characteristics	Tabular data - reservoir type, volume, purpose of water use, share of water designated for use in agriculture	Slovenian National Committee on Large Dams (SNCLD), SEA
Groundwater	Water body	Polygon layer Hydrogeology, water availability	Geological Survey of Slovenia (GSS)
	Borehole	Drilling price	
	Water rights	Geo-referenced tabular data – water abstraction ($m^3 s^{-1}$) and % of all estimated water in groundwater body	SEA, GSS
Accumulated surface runoff	Runoff	Raster layers (mm $year^{-1}$)	SEA
	Mean monthly flow	$m^3 s^{-1}$	
	Mean monthly specific runoff	$l s^{-1} km^2$	IWRS
	Soil data	Polygon layer Soil properties (texture, horizons, bedrock, hydraulic conductivity, soil water capacity, hydrological group)	University of Ljubljana - Biotechnical Faculty (UL-BF)
	Curve number	Share of precipitation as surface runoff defined by land use and soil hydrological group, slope	
	Surface runoff yield and abundance	Quantity of water in millimetres and $m^3 ha^{-1}$	IWRS UL-BF
	DEM	Raster layer - Digital elevation model - 25m	The Surveying and Mapping Authority of the Republic of Slovenia (SMARS)
Irrigation	Irrigation area	Polygon layer	UL-BF
	Irrigation norm	Gross irrigation norm in millimetres, litres or m^3 of water per hectare for defined crop and soils in one year for optimal growing conditions	IWRS, UL-BF
	Hydro-module	Qualities of water used in litres per second per hectare of crop in one irrigation cycle	UL-BF
	Irrigation systems	Polygon layer Total area and actually irrigated land	Statistical Office of Slovenia (SOS)
Land use	Graphical Units of Agricultural Land - GERK	Polygon layer Land cover classification and spatial representation	Ministry of Agriculture and the Environment of the Republic of Slovenia (MAERS)

Table 1. Input data sources for water resources availability assessment

2. Materials and methods

2.1. Input data

Table 1 provides an overview of the data used for spatial analysis (data type, name, source - location, description). If certain type of map was not available we created maps from tabular data provided from different sources. This type of spatial analysis requires a wide range of data starting with land use classes and soil types and their position in space as these have primary impact on surface runoff, percolation of water to groundwater and on soil water content.

Input data also includes river network, river flow, water abstraction and available water quantities for irrigation and ecologically acceptable flow to represent surface watercourses. Additional inputs include data on reservoir characteristics for spatial representation of large water reservoirs. Groundwater data includes hydrogeology and water availability layers, borehole drilling prices and water rights. The widest range of data was needed to spatially represent accumulated surface runoff. We included in the analysis runoff, mean monthly flow, mean monthly specific runoff, soil data, curve number and irrigation areas and norms which resulted in surface runoff yield and water abundance calculations. Geographic Information System ArcGIS software version 9.3 was used for all spatial analyses. Due to the characteristics of the spatial analysis with the raster layers (raster cells) we used extension build in the ArcGIS program toolbox called Spatial Analyst Tool.

2.2. Study area agricultural land

The case study area is the Republic of Slovenia (2,020,318 ha), situated in central Europe between Italy, Austria, Hungary and Croatia. A land use analysis showed that agricultural land potentially suitable for irrigation covers 221,355 ha or 10.3 % (Figure 1, Table 2) of the country.

Based on a land use map, the following agricultural land use classes [20] were identified as suitable for irrigation:

a. fields and gardens, hops plantations, permanent crops on fields, greenhouses, nurseries, intensive orchards, extensive orchards, other permanent crops,

b. olive groves,

c. plantations of forest trees, uncultivated agricultural land.

Fields and gardens are the most suitable areas for irrigation, especially when crop production is being intensified. Irrigation in areas planted with hops, permanent crops on fields (asparagus, artichokes, rhubarb, etc.), intensive orchards (apple trees, pear trees, etc.), nurseries (fruit trees, vines, olive trees, etc.,) and in greenhouses, is particularly critical for sustainable crop production. Extensive orchards are potential areas where new intensive fruit plantations could be planted or old extensive orchards renewed, both could be irrigated to secure more reliable yield. Olive groves are not generally irrigated in Slovenia. An experimental irrigation system was installed within the project: Adapting technology of production to climatic conditions for achieving high quality yield of olives and olive oil (V4-0557). There are several reasons for the absence of olive grove irrigation in Slovenia: relatively high annual precipitation, grower's belief in the relatively low sensitivity of olives trees to drought, lack of reliable water sources, and the terrain, which makes installation of irrigation equipment expensive. Plantations of forest trees with fast growing species like poplar are usually situated on agricultural land. The reasons for growing forest trees on agricultural land are different (paper industry, hydro-meliorations, land reclamations, ameliorations). However, after harvesting these areas could be allocated for agricultural production. Their suitability is even greater because these areas are usually near water resources. Uncultivated agricultural land is usually excluded from production, due to different types of construction sites, only for a certain time period. After completion of works these areas in the majority of cases return back to agricultural production.

Agricultural land use classes	Area		
	Hectare (ha)	Percent (%) of agricultural land	Percent (%) of Slovenia
Fields and gardens	182,146.76	82.29	8.98
Hops	1,977.91	0.89	0.10
Permanent crops on fields	335.95	0.15	0.02
Greenhouses	130.01	0.06	0.01
Nurseries	47.84	0.02	0.00
Intensive orchards	4,385.30	1.98	0.22
Extensive orchards	23,929.25	10.81	1.18
Olive groves	1,810.83	0.82	0.09
Other permanent crops	416.53	0.19	0.02
Plantations of forest trees	271.39	0.12	0.01
Uncultivated agricultural land	5,903.37	2.67	0.29
Total	221,355.15	100.00	10.92

Table 2. Agricultural land potentially suitable for irrigation in Slovenia

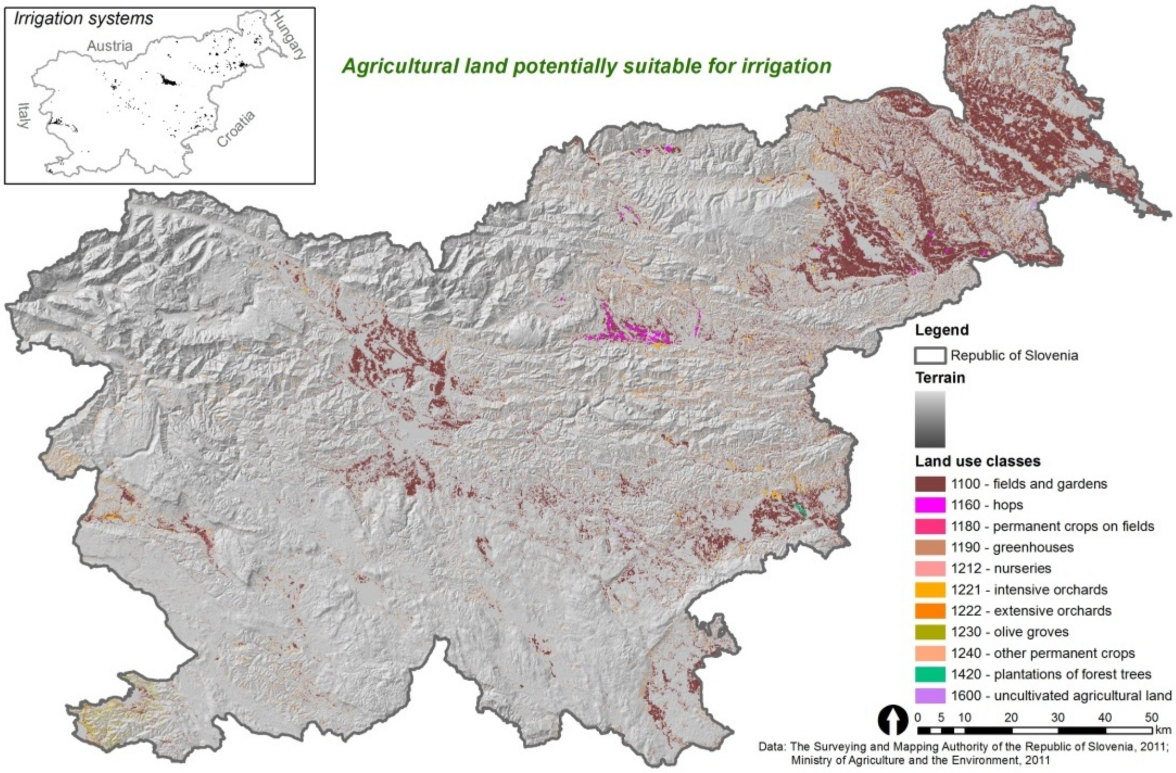

Figure 1. Geographic location of Slovenia, agricultural land potentially suitable for irrigation and locations of irrigation systems

In Slovenia in 2010, of 8,299 ha was prepared for irrigation and, only 3,851 ha was actually irrigated [21], accounting for less than 4 % and 2 % of total agricultural land potentially suitable for irrigation (221,355 ha), respectively (Table 3).

	Year								
	2003	2004	2005	2006	2007	2008	2009	2010	2011
Land prepared for irrigation (ha)	6,339	5,303	4,727	5,395	7,876	7,732	7,841	7,604	8,299
Actually irrigated land (ha)	2,741	2,329	1,812	2,837	3,759	3,651	3,732	3,501	3,851

Table 3. Total area (ha) of agricultural land prepared for irrigation and actually irrigated in Slovenia

2.3. Surface watercourses and large water reservoirs

Water accessibility classes for surface watercourses or water reservoirs were spatially defined and created from the percentage (%) of defined agricultural land use areas suitable for irrigation (Figure 2 and 3). The project on water perspectives (V4-0487) [8, 18] defined the percentage of area that can be directly irrigated from existing water reservoirs. Dry water reservoirs were excluded from the analysis. The analysis was supported with field work (questionnaires) checking the status and operational management of reservoirs and with analysis of regulations on operation and maintenance of reservoirs.

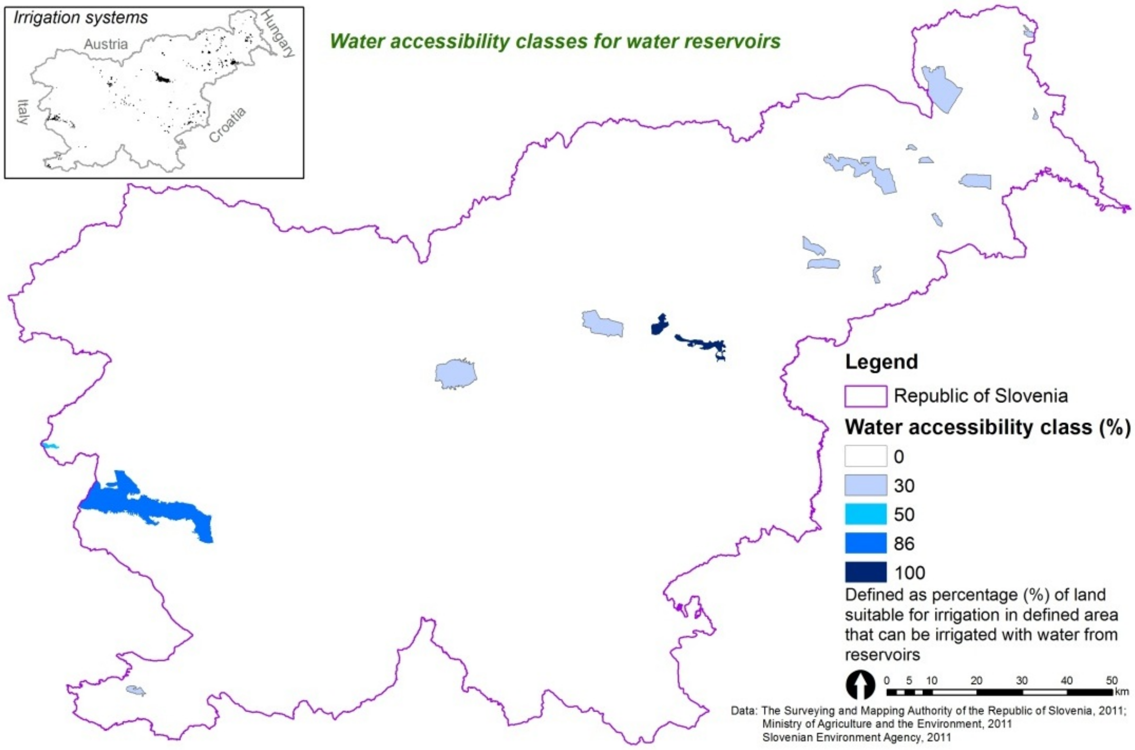

Figure 2. Water accessibility classes for water reservoir in Slovenia

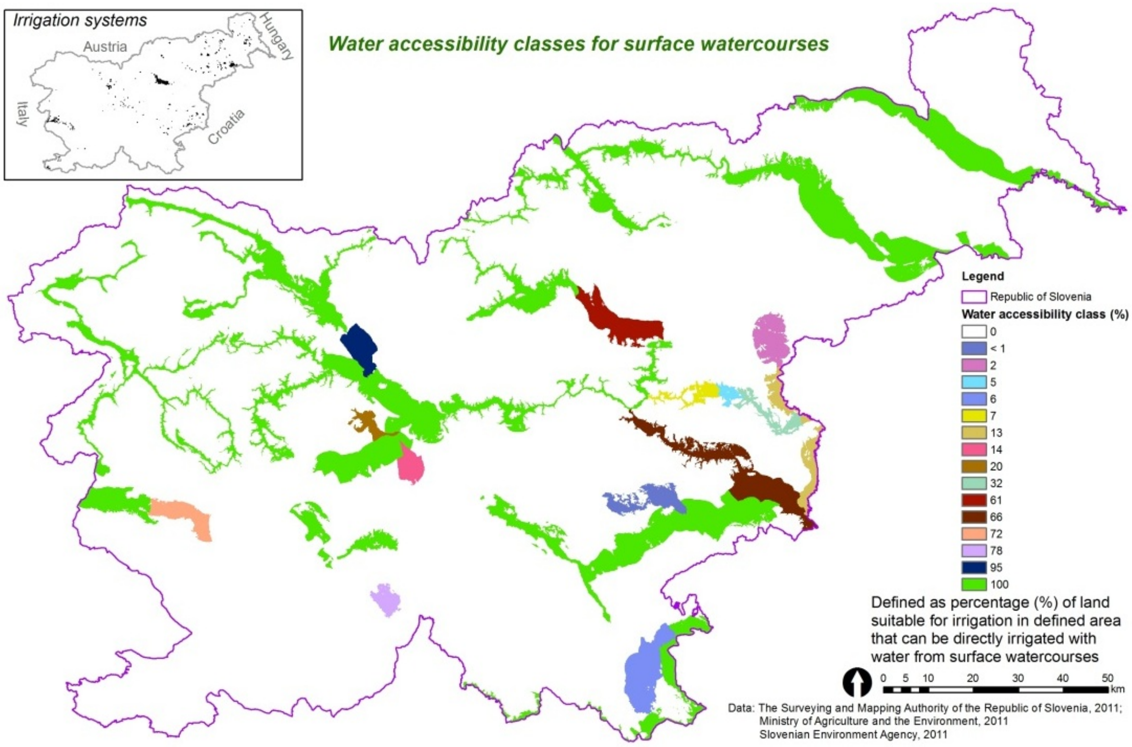

Figure 3. Water accessibility classes for surface watercourses in Slovenia

The project identified eighteen (18) water reservoirs, from which at least part of the accumulated water could be allocated for irrigation of agricultural land. In all of the large water reservoirs impact areas were determined, where water quantities are sufficient for direct irrigation of at least 30 % of the agricultural land potentially suitable for irrigation (Figure 2). It follows that the use of water from certain water reservoirs is quantitatively limited to water available for irrigation of agricultural land.

The percentage (%) of the area that can be directly irrigated from surface watercourses was determined on the basis of the available water quantity for irrigation at the last point downstream of individual surface watercourse water body. The project defined seventy (70) areas suitable for irrigation (Figure 3).

Area determination followed the criteria [18] below:

- maintenance of ecologically acceptable flow (Official Gazette RS, No. 97/2009),
- water abstraction within each catchment area must not be greater than the available water quantity at the last point downstream of individual catchment area of surface watercourse water body,
- total water abstraction within a system of catchment areas must not be greater than the total capacity of a set of catchment areas, which is the same size as the availability of water quantity in the final (outflow) node of the concerned system of catchment areas;
- irrigation area of each watercourse is located in the catchment area of the surface watercourse water body (some exceptions);
- horizontal distance from the river to the border of agricultural land area potentially suitable for irrigation is not greater than 3 km (some exceptions);
- difference in height between the watercourse and agricultural land suitable for irrigation does not exceed 100 m.

Water accessibility points for water reservoirs and watercourses were determined by the extent of agricultural land (ha, %), which may be irrigated with the water assigned for the agricultural use from both sources. It is important that the use of water from a reservoir is quantitatively limited to the water available for agricultural land irrigation, and water from watercourses is limited to ecologically acceptable flows.

Large water reservoirs and surface waters are attributed with 100 points of availability if the water resource supplies sufficient quantities of water for irrigation of all potentially suitable agricultural land for irrigation in the defined area of the water body (Table 4). If water quantities are insufficient (0 to 99%) for irrigation of a whole defined area of water body adequate for irrigation, the water resource is attributed with availability points between 0 and 99.

2.4. Groundwater

Water accessibility classes for groundwater were determined based on a hydrogeological map [22] which defines three classes of groundwater availability (hard, medium and easy) which were

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linked with three classes of average cost for borehole (well) drilling. The areas with easily accessible groundwater and the lowest price for borehole drilling were attributed with 100% availability of water (Table 4). The other two accessibility classes have smaller or higher number of percentages (Figure 4), in proportion to the price of borehole drilling and the accessibility of groundwater.

It is important to note that groundwater is priority reserved for drinking water. A relatively small percentage of groundwater is actually abstracted; with the highest rate (35%) in the Savska kotlina with Ljubljansko barje in central Slovenia. However, the analysis of the officially assigned abstraction rates from granted water rights showed that three groundwater bodies are 100% utilized (Savska kotlina with Ljubljansko barje. Kamniško-Savinjske Alpe in central Slovenia and Vzhodne Slovenske gorice in eastern Slovenia).

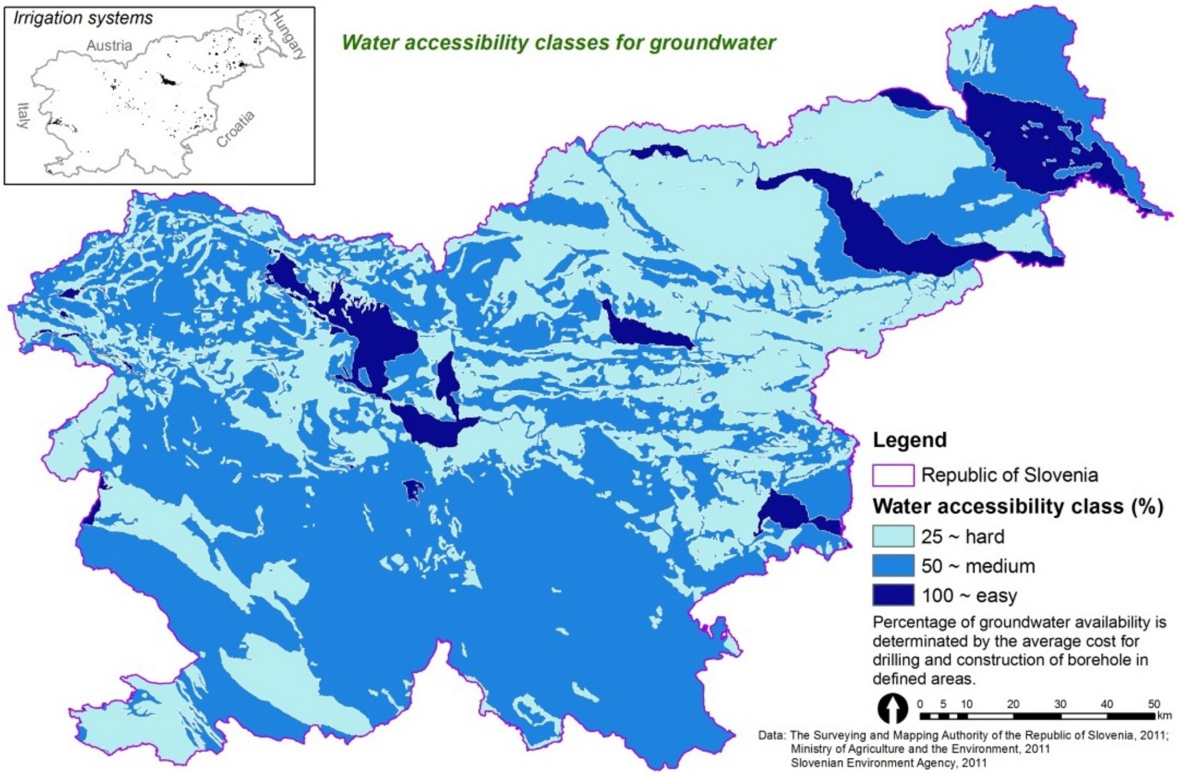

Figure 4. Water accessibility classes for groundwater in Slovenia

The average price for borehole drilling in 2010 in an area with easily accessible groundwater (diameter 100 mm, the average rate of flow of 5.5 l s^{-1}, depth 50 m) was estimated to be 11,000 EUR. The average price for borehole drilling in an area with medium accessible groundwater (diameter 100 mm, yield up to 5.5 l s^{-1}, depth of 70 m to 150 m) was estimated to be 15,000 and 30,000 EUR. The average price for borehole drilling in areas with hard accessible groundwater (diameter 100 mm, the average yield of 1 l s^{-1}, at least 200 m depth) was estimated to be 44,300 EUR. Accessibility of groundwater and price of borehole drilling is highly dependent on geology, groundwater levels, aquifer layer thickness and type of aquifer.

Water resource	Water accessibility and abundance	Water availability points					
Large water reservoirs							
	unrestricted (irrigation of 100% of area[1])	100					
	restricted (irrigation of 0 to 99% of area)	0-99					
Surface watercourses (rivers, streams)							
	unrestricted (irrigation of 100% of area)	100					
	restricted (irrigation of 0 to 99% of area)	0-99					
Groundwater - customized to geology and borehole drilling costs							
	easy	100					
	medium	50					
	hard	25					
Surface runoff as small water reservoirs - customized to winter yield, maximal irrigation norm, light soils and drip irrigation							
	abundance ($m^3 ha^{-1}$)	1 MED	2 PAN	3 SMED	4 SPAN	5 CENT	6 ALPS
	> 6000	- [2]	-	100 [3]	-	100	100
	4000-6000	75	-	100	100	100	100
	2000-4000	50	75	75	75	100	100
	1000-2000	25	50	50	50	75	100
	500-1000	25	25	25	25	50	100
	< 500	25	25	-	25	-	-
	Relative slope < 6 %	0	0	0	0	0	0
No accessible water resource		0					

MED – Mediterranean irrigation area; PAN – Pannonian irrigation area; SMED – Sub-Mediterranean irrigation area; SPAN – Sub-Pannonian irrigation area; CENT – Central Slovenian irrigation area; ALPE – Alpine-Dinaric irrigation area

[1] irrigation of x% of area identified as suitable for irrigation from large water reservoir and surface watercourses

[2] class of winter yield abundance does not exist for certain irrigation area

[3] winter yield abundance of surface runoff from 1 ha of land is sufficient for irrigation of 1 ha of permanent crop (orchard)

Table 4. Determination of potential availability of water resources for irrigation based on water direct accessibility from (1) water reservoirs, (2) surface watercourses, (3) groundwater and (4) abundance of surface runoff yield as small water reservoirs

Areas with easily accessible groundwater and therefore with the lowest price of borehole drilling are attributed with 100 points of availability (Table 4). Medium and hard accessible groundwater areas are attributed with 50 and 25 availability points, respectively. The price of borehole drilling for those two classes is two or four times higher than for easily accessible groundwater.

2.5. Accumulated surface runoff

To create classes of potential abundance of surface runoff for accumulation in small reservoirs, we had to gather information on the maximum irrigation norm for drip irrigation on light soils for several groups of plants per one hectare (vegetables - low norm, vegetables – high norm, strawberries and permanent crops). This was for all irrigation areas and based on the average

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quantity of water available for irrigation (Table 4 and 5) [6, 23]. The definition was also based on the optimum volume of a small reservoir for the irrigation of one hectare (of accumulated surface runoff) defined by agro-meteorological stations in different irrigation areas for a dry year with a five-year return period (Table 4). Classes of potential winter yield of surface runoff (mm) (1971 - 2000) (Figure 5) were merged with a map of irrigation areas creating classes with assigned attributed points of surface runoff yield abundance [24].

Irrigation area	Volume of reservoir (m^3)			Groups of crops	Maximal irrigation norm (m^3)	Water availability points
	Optimal	Average loss	Average available for irrigation			
MED	1500	531,8	968,2	strawberries	878	25
	2000	692,4	1307,6	vegetables – low norm	1292	50
	4500	1477,4	3022,6	vegetables – high norm	2871	75
	6000	1941,2	4058,8	permanent crops	3720	100
PAN	1500	219,5	1280,5	strawberries	1125	25
	2000	284,2	1715,8	vegetables – low norm	1625	50
	4000	536,7	3463,3	vegetables – high norm	3097	75
	4500	598,9	3901,1	permanent crops	3482	100
SMED	1000	131,1	868,9	strawberries	588	25
	1500	187,3	1312,7	vegetables – low norm	1031	50
	2500	296,8	2203,2	vegetables – high norm	2271	75
	3000	350,7	2649,3	permanent crops	2359	100
SPAN	1000	168,4	831,6	strawberries	951	25
	1500	241,0	1259,0	vegetables – low norm	1299	50
	3000	452,1	2547,9	vegetables – high norm	2568	75
	3500	521,3	2978,7	permanent crops	3024	100
CENT	500	45,0	455,0	/	/	25
	1000	80,8	919,2	strawberries vegetables – low norm	552 848	50
	1500	115,3	1384,7	vegetables – high norm	1697	75
	2500	182,3	2317,7	permanent crops	2157	100

MED – Mediterranean irrigation area; PAN – Pannonian irrigation area; SMED – Sub-Mediterranean irrigation area; SPAN – Sub-Pannonian irrigation area; CENT – Central Slovenian irrigation area; ALPE – Alpine-Dinaric irrigation area

Table 5. Determination of availability points for accumulated surface runoff water in small water reservoirs based on average available water for irrigation in reservoir and maximal irrigation norm for drip irrigation and light soils

The magnitude of the abundance points was based on the maximum irrigation norm (drip irrigation) for one hectare of permanent crops (orchards) on light soils and its corresponding optimal reservoir volume for irrigation. If there was enough water for the irrigation of this type of crop (orchard, light soils, drip irrigation, maximum irrigation norm) in an irrigation area it was given 100 availability points (Table 4). Each subsequent class was determined by

25 availability points less, as it does not facilitate sufficient quantities of surface runoff water for irrigation of all groups of agricultural plants.

The determination of abundance points in the case of irrigated land for the Mediterranean and central Slovenian irrigation areas was as follows.

For the drip irrigation of one hectare of permanent crop with maximum irrigation norm on light soils (3,720 m^3 ha^{-1} per year) and water balance for a dry year with a five-year return period we need a small reservoir with optimal volume of 6,000 m^3 of water (Table 5). This means that in the Mediterranean area, where potential accumulated surface runoff yield is more than 6,000 m^3 ha^{-1}, it is possible to irrigate most of the crops. Therefore this abundance class was attributed with 100 availability points (Table 4). If it is possible to accumulate only up to 1000 m^3 ha^{-1} of surface runoff yield in the Mediterranean irrigation area in 'dry year with five-year return period', then only a small share of crops can be irrigated. This means that the water quantity is insufficient to meet the water needs of the majority of crops in this area. Irrigation of strawberries in the Mediterranean area requires 1,500 m^3 of water. Accordingly, this abundance class was attributed with 25 availability points (Table 4 and 5). In central Slovenia, for the drip irrigation of one hectare of permanent crop with maximum irrigation norm on light soil, 2,157 m^3 ha^{-1} per year of water (dry year with five-year return period) is needed. If we include the water balance of the area, a small reservoir with volume of 2,500 m^3 would be needed. This means that in central Slovenia where potentially accumulated surface runoff yield exceeds 2,000 m^3 ha, the abundance classes were attributed with 100 availability points (Table 4 and 5).

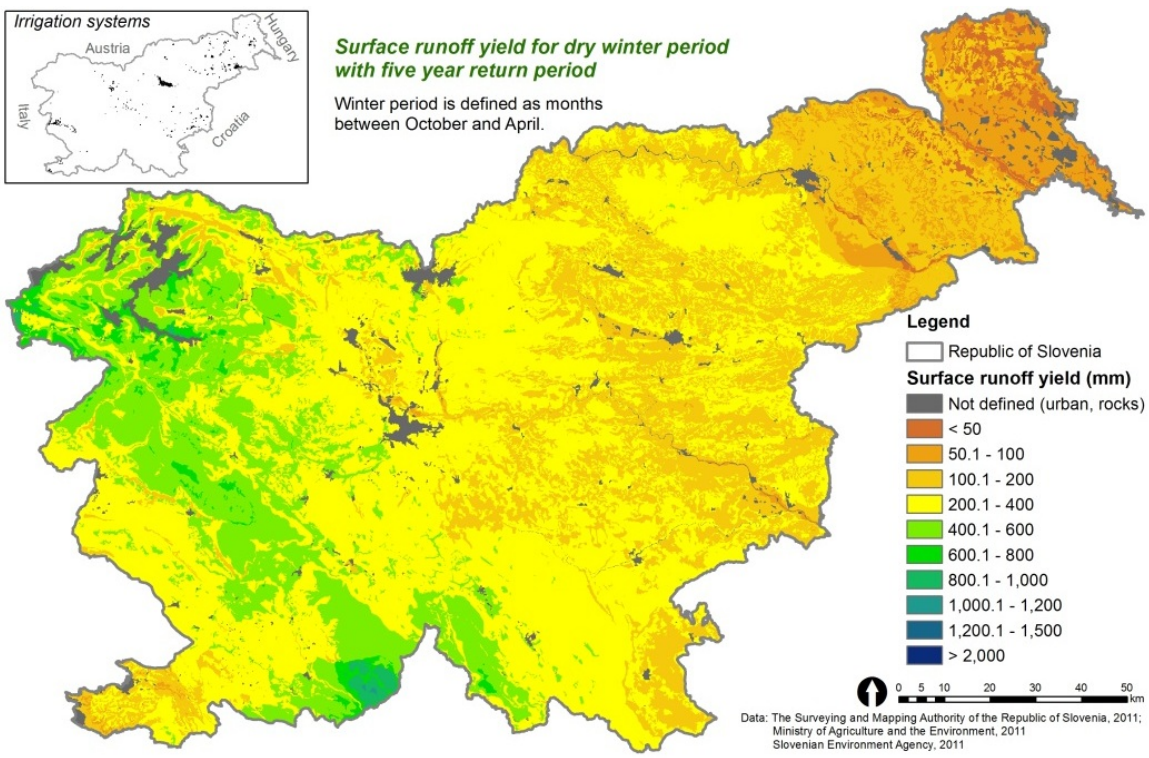

Figure 5. Potential surface runoff yield (mm) for dry winter period with five year return period in Slovenia

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The final product of assembly and reclassification of individual data resulted in a map of abundance classes of potential surface runoff yield for the dry winter period and irrigation norm by irrigation areas (Figure 6). Also excluded from further analysis was data with a relative slope of less than 6%, and undefined areas (urban, rocky, surface waters). These areas were attributed with 0 availability points.

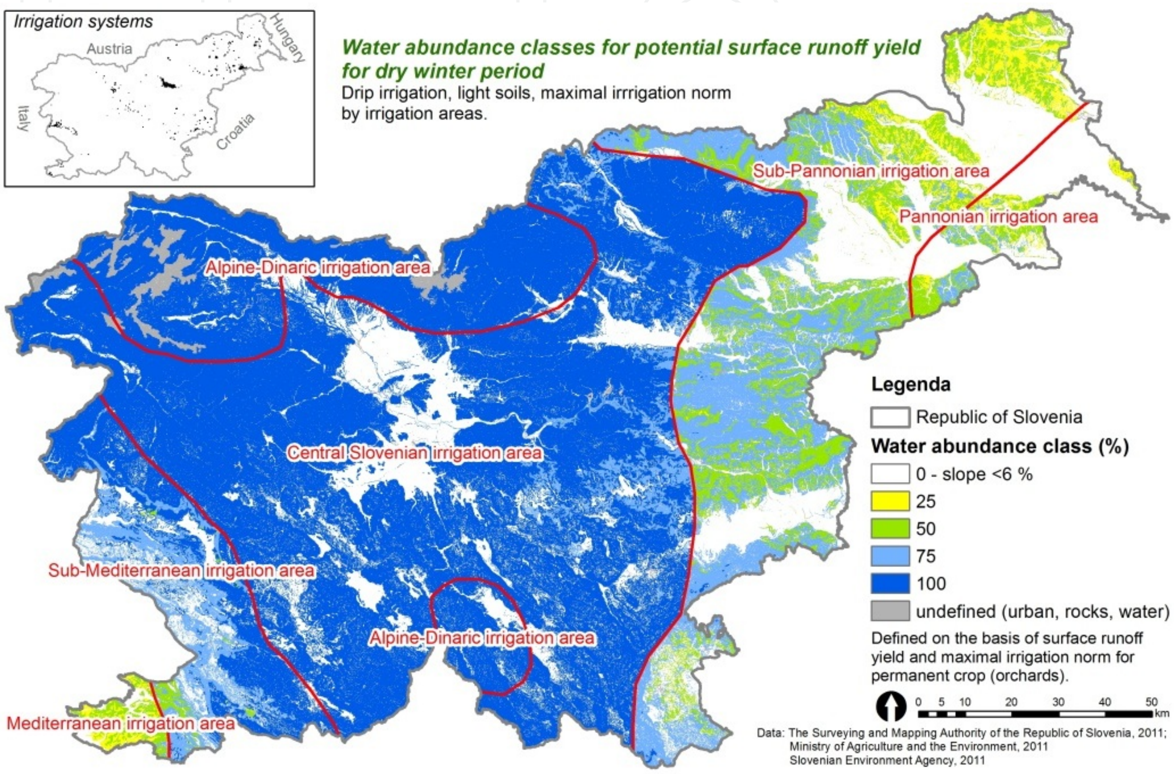

Figure 6. Water abundance classes for potential surface runoff yield for dry winter period in Slovenia

2.6. Drought risk classes definition

The determination of drought risk classes of agricultural land suitable for irrigation is the sum of the attributed availability points of each individual water resource suitable for irrigation of agricultural land (Table 6). Water resources (large water reservoirs, surface watercourses, groundwater and surface runoff yield) are spatially defined and interrelated (Figures 2 - 6). The analysis was conducted with raster layers whose spatial resolution was 100×100 m (1 ha) for the entire study area.

Drought risk assessment for agricultural land suitable for irrigation is divided into 6 classes (Table 6). Class 1 is attributed with zero points and indicates areas with potential absence of available water resources for irrigation and is defined as an area with 'distinct drought risk'. Class 6 is attributed with 400 availability points, as all water resources (included in the research) are potentiality available for irrigation and is defined as area with virtually no drought risk if proper measures are undertaken. Intermediate classes between 2 and 5 have one or more restricted water resources and/or one or more of the unlimited water resources suitable for irrigation.

Class		Sum of points	Definition of water resources availability
Number	Drought risk		
1	Distinct	0	No available water resources
2	Very high	1 - 99	Only water resources with limited availability
3	High	100 - 199	One water resource with unlimited availability and/or more with limited availability
4	Medium	200 - 299	Two water resources with unlimited availability and/or more with limited availability
5	Low	300 - 399	Three water resources with unlimited availability and/or more with limited availability
6	None	400	All water resources with unlimited availability

Table 6. Determination of risk classes of agricultural land suitable for irrigation in case of drought from the sum of availability points of water resources for irrigation

3. Results

Due to the characteristics of the spatial analysis of the raster layers (raster cells) with the ArcGIS program tool (Spatial Analyst Tools), areas of certain land use classes and total area of agricultural land suitable for irrigation were slightly lower in comparison with the real situation. However, in the results section we primarily operate with shares of areas, describing availability points of water resources and drought risk classes.

3.1. Water resources availability assessment

Slovenia has unevenly distributed water resources suitable for irrigation as can be seen from the spatial analysis of availability points (Figure 7) in terms of the dry year with five-year return period.

We detected high availability (151-399 points) of water resources for irrigation in river valleys with alluvial soils (rivers Sava, Drava, Mura, Krka and Vipava), where there is, in addition to surface watercourses, also an easily accessible groundwater and in certain areas (river Vipava) large reservoirs (10 % of case study area) (Table 7). In more than 69 % of the case studies water resources for irrigation is rather poorly available (only 100-151 points), which are mostly a combination of groundwater and surface runoff. On more than 17 % of case study areas, available water resources are extremely low (25 - 99 points), with nearly 3 % of area having only low available groundwater (less than 25 points), whose availability for irrigation is in question due to the high costs associated with borehole drilling.

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Availability points classes	Area	
	ha	%
Undefined (urban, rocks, water)	60.896,5	3,01
0	0	0,00
1 - 25	54.137,5	2,68
26 - 50	173.185,7	8,57
51 - 99	122.795,3	6,08
100 - 150	1.406.312,6	69,61
151 - 199	34.017,6	1,68
200 - 250	154.698,3	7,66
251 - 299	7.758,8	0,38
300 - 350	6.401,5	0,32
351 - 399	114,3	0,01
400	0	0,00
Total	**2.020.318,1**	**100,00**

Table 7. Areas (%, ha) classes of availability of water resources for irrigation based on figure 7 for total area of Slovenia

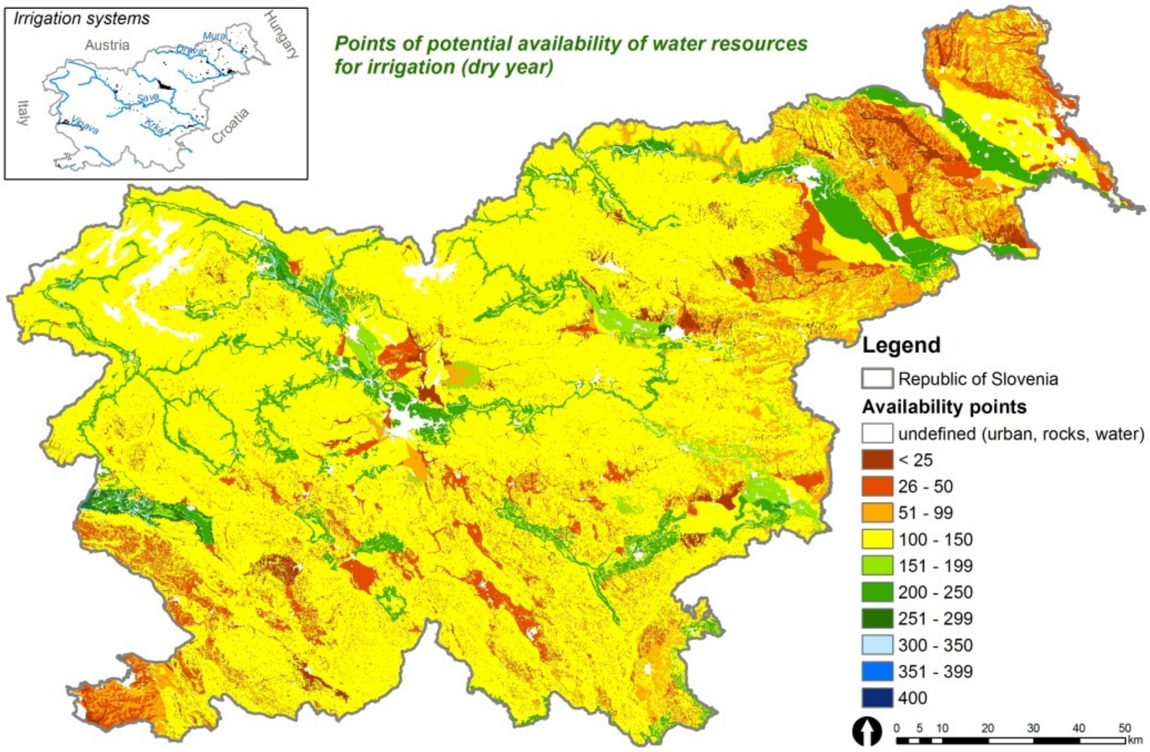

Figure 7. Points of potential availability of water resources for irrigation (based on table 3) in Slovenia at 1 ha resolution (100×100 m); dry year with five years return period (80-90 % probability of occurrence)

3.2. Drought risk assessment

The map of potential availability of water resources for irrigation was further adjusted and classified in accordance to the potential drought risk (Table 6), thus creating a map of agricultural land suitable for irrigation yet exposed to drought risk at the dry year with five year return period (Figure 8).

We conducted a spatial analysis of agricultural land suitable for irrigation in the case study area to define the availability of water resources for irrigation, and to define potential areas of drought risk. We identified areas of agricultural land at none, low, medium, high, very high and distinct drought risk. Analysis of the potential drought risks of agricultural land suitable for irrigation showed that more than 34 % (75,868 ha) of the case study agricultural land suitable for irrigation is located in areas of very high drought risk (1 - 99 points). Nearly 50 % of agricultural land (109,231 ha) is located in areas of high drought risk (100-199 points) and almost 15 % (33,010 ha) in areas of medium drought risk (200 - 299). Low drought risk (300 - 399) is present in only 0.2 % of agricultural land (442 ha) and is therefore negligible at the macro scale. Based on this analysis we argue that areas of medium and low drought risk should not suffer from water scarcity or drought causing damage in crops production and limiting crop yield, if appropriate infrastructure and systems for water transport and irrigation are installed, maintained and used in these areas. Research analysis did not detect any areas of agricultural land use suitable for irrigation at either absolute extremity of drought risk (0 points and 400 points).

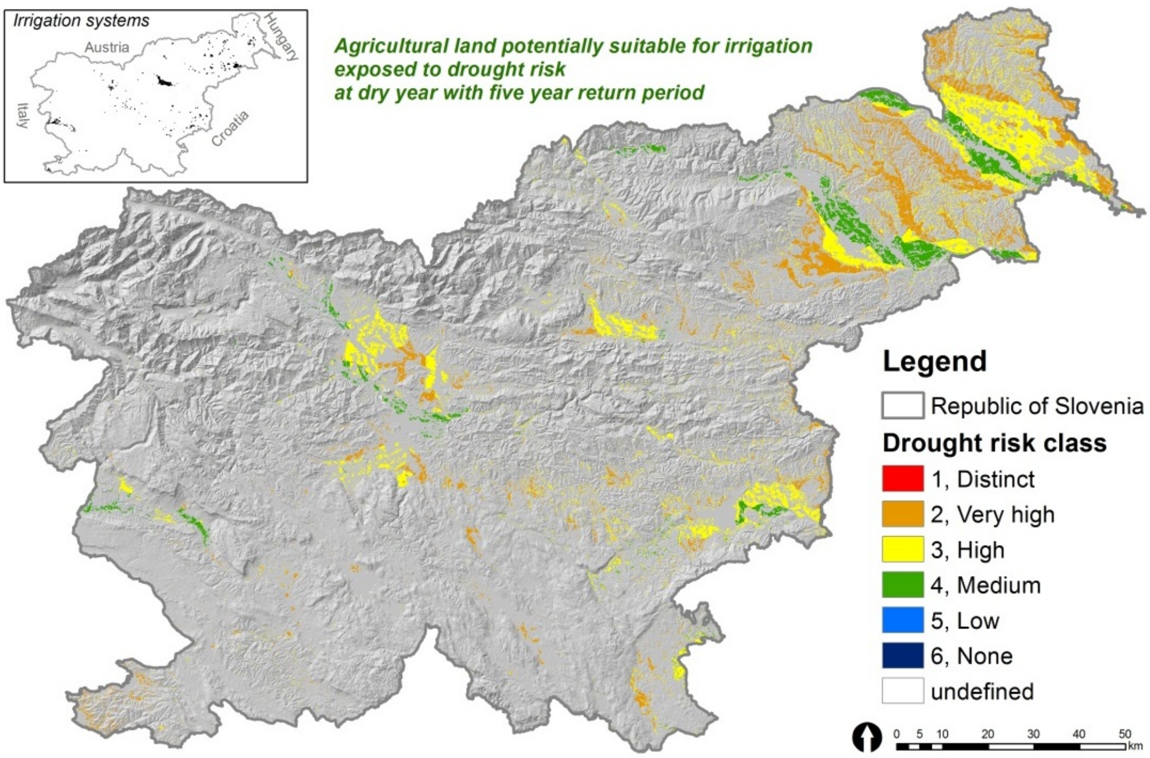

Figure 8. Agricultural land potentially suitable for irrigation and exposed to drought risk at dry year with five year return period in Slovenia at 1 ha resolution (100×100 m) (based on table 4)

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4. Conclusions

This chapter presents a novel methodological approach and findings which substantially contribute to the understanding of spatial water resources availability and drought risk assessment of agricultural land. The methodology is clear, practical and therefore generally applicable in any region or on a global level. Methodology is open to adding other water resources, not presented here (e.g. waste water), in to the water resources availability assessment.

When the spatial analysis of available water quantities for irrigation from water resources is prepared for a certain area (region, state, catchment), it is essential to cooperate with all organizations engaged in regulating water management (e.g. environmental agencies, water and geological institutes and responsible governmental bodies). Water quantities available for irrigation from different water resources are usually regulated by state legislation defining minimal water quantities in the surface watercourses or reservoirs to sustain ecological acceptable flows, for the survival of the organisms in the water bodies. Legislation should also include consideration of the share of total water quantity in the water body which can be abstracted for irrigation of agricultural land, and the share of the water quantity in the water body at ecological acceptable flow that is especially reserved for agriculture and can be abstracted for irrigational purposes. Water reservoirs usually have, in addition, operational regulations defining the share of water reserved for agriculture, recreational activities, or for the conservation of wildlife habitats. Legislation and regulation are key factors to preventing over exploitation of water resources.

Spatial analysis of potentially needed water quantities for irrigation should be based on land use classes, types of crops and crop management. This is especially important in the case of crops with high water demand. Furthermore, spatial analysis should include physical and hydrological properties of soils in the area. This is important if soils in the area are light, with a high share of sand, high hydraulic conductivity and low available water capacity. Finally, it is crucial to define the irrigation norm (maximum, average and minimum) for all types of soils and crops grown in the area. This kind of analysis has to be done in cooperation with soil hydrologists, plant physiologists, agro-meteorologists and specialist technicians in irrigation systems.

To define accessibility or abundance of water resources in this study, we choose to use availability points as a number from 0 to 100. Water accessibility points for water reservoirs and watercourses were determined by the extent of agricultural land (%), which may be irrigated with the water assigned for agricultural use from both sources (0 to 100 points). Water accessibility classes for groundwater were determined on the basis of the hydrogeological map and average cost for borehole drilling, and put into three classes: hard (25 points), medium (50 points) and easy (100 points), defining the availability of groundwater. The determination of abundance points was based on the maximum irrigation norm (drip irrigation) for one hectare of permanent crops (orchards) on light soils and its corresponding optimal reservoir volume for irrigation. If in irrigation area was enough of water for irrigation of orchard on light soils with drip irrigation and maximum irrigation norm, it was given 100 availability points (Table 4). Each subsequent class was determined by 25 availability points less, as it does not facilitate sufficient quantities of surface runoff water for irrigation of all groups of agricultural plants.

Drought risk classes have to be developed in a careful manner with a clear distinction between classes. A maximum of six classes is recommended, to maintain comprehensibility and transparency for the reader. Aggregation of classes is useful, but must include sufficient information for the reader to understand the data. The scale needs to have extreme classes which represent areas without potentially available water resources for irrigation and areas with all potential water resources fully available.

Practical applications of the geospatial analysis of water resources for sustainable agricultural water use are numerous. The results are important for identifying areas on regional and global level which are best suited for irrigation development in terms of water resources availability. Results are important as they help areas suffering from periodic droughts to draw governmental attention. This is important as these areas require financial investment in irrigation equipment and irrigation technologies. It helps small growers in remote hilly or karst areas to identify reliable water resources. The results define areas suitable for building small water reservoirs for accumulated surface runoff water, which can help small farm businesses with vegetable or fruit production to be water independent in the drought periods. This is especially important for the population and agriculture businesses in dry, temperate and continental climates with high seasonal differences in precipitation and evapotranspiration.

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Author details

Matjaž Glavan, Rozalija Cvejić, Matjaž Tratnik and Marina Pintar

University of Ljubljana, Biotechnical Faculty, Agronomy Department, Chair for Agrometeorology, Agricultural Land Management, Economics and Rural Development, Ljubljana, Slovenia

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