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Seasonality in the alpine water logistic system on a regional basis

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Abstract

In this study the water logistic system is defined as the interaction of the subsystems water resources, water supply and water demand in terms of water flow. The analysis of a water balance in alpine regions is strongly influenced by both temporal and spatial seasonal fluctuations within these elements, the latter due to the vertical dimension of mountainous areas. Therefore the determination of different seasons plays a key role within the assessment of alpine water logistic systems. In most studies a water balance for a certain region is generated on an annual, monthly or classic 4-seasonal basis. This paper presents a GIS-based multi criteria method to determine an optimal winter and summer period, taking into account different water demand stakeholders, alpine hydrology and the characteristic present day water supply infrastructure of the Alps. Technical snow-making and (winter) tourism were identified as the two major seasonal water demand stakeholders in the study area, which is the Kitzbueheler region in the Austrian Alps. Based upon the geographical datasets mean snow cover start and end date, winter was defined as the period from December to March, and summer as the period from April to November.

1 Introduction

1.1 Alpine seasonality

Pre-alpine and alpine catchments are characterized by great temporal and spatial variations in climatic elements. Strongly depending on altitude, the runoff of alpine catchments is influenced by glacier melt, snow accumulation and snowmelt (Gurtz et al., 1999). During the melt season snowmelt and glacier melt contribute considerably to the total discharge and considerable quantities of water are stored in winter. With alpine hydrology being very dependent on seasonal variation, the water demand also shows very large temporal fluctuations, largely due to tourism – especially winter tourism.

The aim of this study is to determine the seasonality of these elements in order to determine the water balance for a regional water management analysis. For this purpose the management of the alpine drinking water system is handled as part of the total water system, taking into account water resources, water demand and the typical alpine water supply (system). An outlook to this integrated water logistic concept for the sustainable use and management of alpine water resources was described by Fleischhacker (1994).

The goal of this study is to determine an optimal winter and summer season, for which the water balance variability within the water logistic system is reduced to a minimum. The generation of a monthly water balance becomes unnecessary for many considerations, and the approach of an annual water balance not taking into account alpine seasonality is put aside. Depending on their aims and locality, other studies defined winter and summer seasons in different intervals. Tappeiner et al. (2001) defined the winter season for the alpine upper Passeier Valley in Italy from November to May. Soulsby et al. (1997) analysed the seasonal snowpack influence on the hydrology of a catchment in the Scottish Cairngorm Mountains, and defined winter from October to March. Also Christensen and Lettenmaier (2007) defined winter from October to March, and summer from April to September.

1.2 Water supply

In Austria, especially in alpine Regions, drinking water supply systems are characterised by a local, small structured infrastructure. In general, water supply is organised on a municipality basis. A total of 7600 public water supply undertakings provide the national population of 8.1 Mio. inhabitants with drinking water, resulting in an average number of 900 inhabitants served per undertaking, with a connection percentage of 88% (Schoenback et al., 2004). However, 5.2 Mio. inhabitants are served with drinking water by a total of only 190 major undertakings. In the project area of the greater Kitzbueheler region, a typical rural Alpine region, each of the 20 municipalities has its own drinking water supply infrastructure. Additional to the larger municipal water supply organisations a high number of small water co-operatives serve about 10% of the inhabitants. Water pipe connections between the different supply systems are very rare. These structures have developed during the past century mainly due to the typical characteristics of alpine valleys, where the population is densely concentrated on a small area, competing with other stakeholders like agriculture. Mind, in the Austrian Province of Tyrol, a mere 13% of the total surface is considered to be suitable for human settlements.

1.3 Water resources

The seasonality of hydrological elements in alpine regions is highly dependent on altitude (Merz and Bloeschl, 2003). The seasonality of monthly discharges is influenced by snow accumulation in winter and snowmelt in spring. The duration of snow cover influences the ground water recharge (Schoener and Mohnl, 2003). The availability of water resources in form of surface and spring water is therefore generally lowest in winter, the period where typically low flows occur. According to Smakhtin (2001), in cold or mountainous regions, in addition to the usual catchment parameters, low flows are subject to the special influences of ice and snow melting. Rivers often have their lowest flows in winter due to the temporal storage of precipitation as snow. As a consequence, the analysis of low flows and base flows are possible procedures in the estimation of ground water recharge (Froehlich et al., 1994).

Lahaa and Bloeschl (2006) investigated for 325 subcatchments in Austria seasonality indices for regionalizing low flows, defined as q_{95} in mm/a, i.e. the specific discharge that is exceeded on 95% of all days at a particular site. According to the authors, Austria is divided into an alpine region where low flows are dominated by winter processes and into flatlands and hilly terrain where low flows are dominated by summer processes. Seasonality analysis of low flows in geographically similar regions like southwest Germany (Schreiber and Demuth, 1997) corresponds in general well to seasonality types of the northern part of Austria as described by Lahaa and Bloeschl (2006). The authors indicate that, in southwest Germany, the annual distribution of precipitation is relatively even with a maximum in summer (June, July, August) and a minimum in late winter (February and March). The mountainous regions have a secondary maximum in winter (December and January). Due to low temperatures, this precipitation is locked as snow and therefore causes low flow periods particularly in winter. Aschwanden and Kan (1999) investigated the long-term characteristic seasonal distribution of q_{95} for different regions in Switzerland, based on the 1935–1996 observation period. Switzerland is geographically very similar to Austria, apart from the higher altitude of the Swiss Alps. The Swiss authors found two typical seasonal distributions of low flows in Switzerland, depending on catchment altitude. In alpine catchments, low flows occur exclusively from November to March.

1.4 Water demand

Winter tourism is one of the most important industries in the Alps (e.g. Abegg et al., 1997; Elsasser and Messerli, 2001; Rixen et al., 2003). In the Austrian Province of Tyrol a total of 41.8 Mio. tourist overnight stays have been recorded for the year 2006, of which 52% occur in the winter months from December to March. The main requirement for successful winter sports is the reliability of snow occurrence in the winter sports resorts. According to Buerki (2000), snow reliability is achieved when a snow cover – deep enough for winter sports (30 to 50 cm) – is present during at least 100 days in seven out of ten winter seasons (1 December to 15 April). In recent years, the production of technical snow (also called "man-made snow") has become an increasingly important issue in most ski areas of the world (Mosimann, 1998; OECD, 2007). Climate scenarios forecast a rise of 300 m in elevation where winter sport is economically viable from 1200 to 1500 m a.s.l. within the next 25–50 years (Buerki, 1998; OECD, 2007). Therefore, ski resorts at elevations lower than 1500 m a.s.l. might not obtain enough snow to maintain a profitable winter sports industry. Due to this reason, mountain railway companies invest increasingly in the production of technical snow. In the European Alps the production of technical snow on a large scale started in the mid eighties (Proebstl, 2006). In 2001, already 7.6% of the total ski pistes area

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in Switzerland was covered with technical snow and the snow production continues to increase (Rixen et al., 2003). In the United States, 59% of all ski resorts already relied on snowmaking in 1984 (Kocak and van Gemert, 1988).

Water, air, energy and temperatures below freezing are required to produce technical snow with most of the common snowing facilities. Usually, temperatures of less than –7°C are required for the water droplets to freeze on their way to the ground (Fauve et al., 2002). If ice nucleates are added to the water, snow can be produced at temperatures up to –3°C (Proebstl, 2006). However, continuous effort is made to develop techniques to make artificial snowing possible for temperatures up to 0°C (Proebstl, 2006).

Water for technical snow production is extracted from streams, lakes, springs, ground water and public drinking water infrastructure. In terms of temporal water demand it is to be differentiated between a base snowing at the beginning of the winter season and improvement snowing during the remaining winter season.

2 Study area

As case study the greater Kitzbueheler Region (Fig. 1), located in the Province of Tyrol, Austria, was chosen. The area encompasses 20 municipalities located in the Eastern Alps, of which two – Kitzbuehel and Sankt Johann – are of urban character, and the remaining municipalities are of a rural character. The highest mountain peak reaches 2533 m a.s.l. There are no glaciers. Tourism is by far the largest industry, with an annual average of 6.5 Mio. tourist overnight stays recorded for the years 2000 to 2006, of which 54% occur in the winter months from December to March. The total population (principal residence) of the region is 60 632 inhabitants (Table 1). Typical for the alpine region, the public drinking water demand is covered by spring water to a rate of 80%, and by ground water to a rate of 20%. Surface water is not used for drinking water purposes.

3 Methodology

The fundamental dataset for the seasonality analysis is a snow cover duration map of the area, which is generated based upon 1) snow measurements at different weather stations and 2) a digital elevation model (DEM) using a spatial interpolation by means of conventional GIS-software. Jansson et al. (2003) stated that snow and ice significantly affect catchment hydrology by temporarily storing and releasing water on various time-scales. The seasonal snow cover causes a time lag between the precipitation event and runoff of typically several months. The alpine character of the study area results not only in a temporal seasonality, but also in a high spatial variability of the snow cover. According to Slatyer et al. (1984) the duration of the snow cover correlates with elevation and exposure. This is confirmed by Schoener and Mohnl (2003), who generated a snow cover map (250 m×250 m) for the entire Austrian area, based upon a spatial interpolation of daily snow depth measurements at 835 climatological stations for the World Meteorological Organization's climate normal period from 1961 to 1990. The authors defined a day as a snow cover day if a complete snow cover of 1 cm (or more) is observed at the measurement site, situated near the climatological station, at a 7 o'clock reading. Days with scattered snow spots were not taken into consideration. A correction of the resulting snow cover was made taking into account the exposition and slope of the area. The maximum correction amounts to a lengthening or shortening of the duration of snow cover up to 14 days in a strongly structured terrain. The authors differentiated between snow cover and winter cover, with the latter defined as the longest continuously existing snow cover of a winter season (minimum depth 1 cm). The analysis in this study is based on the winter cover, but in the remaining text this term will be referred to as snow cover. In most literature only the term snow cover is used.

For the Kitzbueheler study area, a spatial interpolation of mean daily snow cover duration is made for the period 1961 to 1990 for 13 observation stations. The definition of a snow (winter) cover day is taken from Schoener and Mohnl (2003). Of these stations, 12 are located in the valleys at an altitude between 495 m and 980 m a.s.l. and 1 is located in the mountains (Station Hahnenkamm) at an altitude of 1760 m a.s.l. (Fig. 1). The latter is used for a linear regression with altitude, by means of the interpolation algorithm GRADGRID as described by Bucher et al. (2004). In the same way a spatial interpolation of the mean start date and mean end date of the snow cover for the period 1961 to 1990 is made, with the first day of the year defined as 1 September. The 3 resulting geodatasets are interpolated as 250 m×250 m resolution rasters.

Urban water use typically consists of residential, industrial, commercial, and public uses, as well as some minor use for other purposes such as fire fighting. In the study area industry is of minor importance, and industrial buildings are commonly situated outside of the town centre with an own water provision not connected to the public water supply infrastructure. In order to calculate the public drinking water demand in the 20 municipalities, a methodology (Vanham et al., 2007) based upon on the one hand the number of inhabitants and persons employed in different sectors as rasterdata, and on the other hand the number of tourists (recorded as overnight stays) is used. This method accounts for residential, commercial and public water use. As this analysis uses specific population census data in a GIS-raster format only available for the year 2001, the public water demand is calculated for the year 2001. These values are calibrated with operating data of the drinking water supply systems, as collected by means of a questionnaire. These operating data show only small variations in annual water demand over the past 10 years. It can therefore be reasonably assumed that the public water demand stayed stable during this period. The calculations resulted in a total annual water demand of about 5 million m^3 (Table 2), of which overnight stays account for 1.5 million m^3 (30%). The public drinking water demand can therefore be divided in firstly a base water demand (70%), which is in general constant when considered on a annual basis, and secondly a seasonal water demand (30%), which depends on the number and temporal distribution of overnight stays. In reality, water consumption varies seasonally, monthly, daily, and hourly. However, in this study only seasonal water demand needs to be taken into account. The water demand for overnight stays is therefore identified as the first seasonal water demand determining the seasonality in the alpine water logistic system.

The second main water demand affecting the seasonality in the alpine water logistic system is snow-making. Proebstl (2006) evaluated the water demand for snowing in different ski regions of the Bavarian Alps in Germany and the Tyrolean Alps in Austria in similar altitudes as the project area of this study. As a ground rule it is stated that 2.4 m^3 of snow is generated from 1 m^3 of water. For the base snowing at the beginning of the winter season, generally during cold days and nights at the end of November or beginning of December, a snow height of 20 to 35 cm is required, which corresponds to 70 to 120 liter water pro m^2. For improvement snowing during the remaining winter season about 50 to 120 percent of the base snowing is required, depending on the local situation. In this study a base snowing of 35 cm is assumed, as well as an improvement snowing of 120 percent. A geographical dataset of all ski runs with the specification of areas with technical snow making (total area 882 ha) is available. A calculated water demand of 2.3 million m^3 is needed for snow-making (Table 2).

For computing the seasonality in the alpine water logistic system, a GIS-multicriteria approach is chosen to make it possible to account for the two principal seasonal water demand stakeholders snow-making and tourism in relationship to their claimed water resources. The fundamental datasets for this analysis are the mean snow cover start date (SCOV6190_S) and end date (SCOV6190_E) rasters. Multicriteria decision making is defined as choosing among alternatives based on a set of evaluation criteria (Malczewski, 1999; Eastman, 1999). The criteria can include characteristics of geospatial data, such as those used in determining the optimal location for an activity. Multicriteria decision analysis using GIS applies a set of weight factors to each data characteristic. In this study, the evaluation criteria are the SCOV6190_S and SCOV6190_E rasters regarding the 2 seasonal water demand stakeholders and the weight factor is chosen as the demand quantity relationship (i.e. 40% tourist overnight stays, 60% snow-making).

In the study the start and the end of the snow-making season are assumed to collide with the start and the end of the snow cover duration, because a temperature below zero is a basic necessity for both natural and technical snow. Therefore, the start and the end date of the snow cover are taken as the temporal change between the summer and winter season and the winter and summer season respectively with regard to the water demand stakeholder of snow-making. This assumption is a simplification, as in reality snow-making can begin before the start of the snow cover, when the temperature is sufficiently low. However, this period of time can vary from days to only a few hours in the night. Moreover, there is no common legislation to all Alpine countries or even regions within certain countries governing the use of technical snow-making (Proebstl, 2006; OECD, 2007). Legal start dates of the snow-making season among ski-regions of the Kitzbueheler study area – even with their slope base at similar altitudes – tend to differ. After official application to local authorities this legal start date can be changed upon the needs of the ski operator. The choice of the start of the snow cover as a conservative indicator for temperatures below zero can therefore imply a shortening of the realistic snow-making season. On the other hand, snow-making can also stop before the end of the snow cover in spring, as this latter usually persists for some time even in the presence of temperatures that are constantly above zero. The length of this period depends upon air temperature, topography and snow cover characteristics (Kling et al., 2005). This assumption therefore can imply a lengthening of the snow-making season. Nevertheless, the start and end date of the snow cover were chosen as the determining factor for defining the snow-making season in order to simplify the analysis and constrain data requirements.

The different ski regions are weighted by their area of slopes with snow-making in relation to the total area of slopes with snow-making in the study area. While the decisive zone of the ski slope for the seasonality analysis is the lowest zone, this area is selected for the analysis (Fig. 2). This GIS-based analysis is summarised in the equation

$$T_{\text{snow}} = \sum T_i(A_i/A_{\text{snow}}) \quad (1)$$

where T_{snow} is the weighted day or time interval (half month) in the SCOV6190_S or

SCOV6190_E raster for all ski regions within the study area. T_i is the selected day or time interval (half month) in the SCOV6190_S or SCOV6190_E raster for a specific ski region i, as visualised in Fig. 2. A_i represents the ski slope area with snow making for a specific ski region i. A_{snow} is the ski slope area with snow making for all ski regions within the study area.

In order to evaluate the impact of tourism in the form of overnight stays on the seasonality of the alpine water logistic system, the seasonal behaviour of the water resources providing the water supply systems to which hotels and guesthouses are connected, is assessed. As used ground water resources are located in the valleys and as the volume of used groundwater is marginal as compared to spring water (Table 2), only springs are considered in the analysis. In the study area most of the water supply systems are provided with water from more than one spring, which makes it necessary to weight these springs to their relative mean flows. This procedure is visualised in Fig. 3 and summarised in the equation

$$T_{tour} = \sum((\sum T_j(Q_j/Q_k))(O_k/O_{tour})) \quad (2)$$

where T_{tour} is the weighted day or time interval (half month) in the SCOV6190_S or SCOV6190_E raster for all public water supply systems that are (partly) served by spring water within the study area. T_j is the selected day or time interval (half month) in the SCOV6190_S or SCOV6190_E raster for a specific spring j, that provides the water supply system of municipality k with water. Q_j is the mean winter (January–February) flow of spring j. Q_k is the sum of mean winter (January–February) flows of all springs that provide the water supply system of municipality k with water. O_k represents the number of overnight stays connected to the water supply infrastructure for a specific municipality k that is (partly) served by spring water. O_{tour} represents the number of overnight stays connected to the water supply infrastructure for all municipalities in the study area that are (partly) served by spring water.

Based upon the Eqs. (1) and (2), the seasonality in the alpine logistic system for the study area can be analysed according to the equation

$$T_{\text{log}} = D_{\text{snow}} T_{\text{snow}} + D_{\text{tour}} T_{\text{tour}} \quad (3)$$

where T_{log} is the weighted day or time interval (half month) in the SCOV6190_S or SCOV6190_E raster for the alpine water logistics system. D_{snow} represents the relative amount of water demand of the seasonal stakeholder snow-making, in relation to the water demand of both seasonal stakeholders. D_{tour} represents the relative amount of water demand of the seasonal stakeholder tourism in the form of overnight stays, in relation to the water demand of both seasonal stakeholders.

4 Results

The interpolated mean snow cover duration raster (SCOV6190) was verified with the mean snow cover duration raster (both raster period 1961 to 1990 and resolution 250 m×250 m) in the Hydrological Atlas of Austria (Schoener and Mohnl, 2003), and a good correlation (R^2=0.88) between both was found.

The mean snow cover start (SCOV6190_S) and end date raster (SCOV6190_E) (Fig. 4) have been interpolated on a daily basis (i.e. every grid cell defines a specific day of the year), yet for the seasonality analysis they are categorised in half-monthly intervals. The raster SCOV6190_S shows a much shorter temporal and spatial variation (2.5 months from mid October to the end of December) as its counterpart SCOV6190_E (4 months from the beginning of March to the end of June).

As spring flow data are not available for the study area before 1990, a direct relationship between snow cover start and end date with the behaviour of spring flow can only be made by interpolating snow data in more recent winters. More specifically, Fig. 5 shows the relationship between the spring "Schreiende Brunnen" (995 m a.s.l.), located in the municipality of Fieberbrunn, and the interpolated snow cover end date for the winter 1999–2000 (15th of April), a raster that is very similar (Correlation R^2=0.95) with the mean snow cover end date raster of the period 1961–1990. This figure shows clearly the rise in spring flow with ending of the snow cover, as well as the significant lower spring flow and therefore availability of water resources in the winter months.

The GIS-analysis of Eq. (1) for the water demand stakeholder snow-making, based upon the rasters SCOV6190_S and SCOV6190_E, results in a weighted start of the winter season of 0.88 to 1 during the period 1 to 15 December (Table 3). The remaining weighted periods are the two weeks before and after this period. As single day the 9th of December results from the analysis. The second half of March (respectively 23 March) proves to be the optimal end period of the winter season if only taking into account snow-making. The GIS-analysis of Eq. (2) for the water demand stakeholder tourism (in the form of overnight stays) results in a weighted optimal start of the winter season at the beginning of December, and an optimal end of the winter season during the first half of April. The analysis of Eq. (3) defines a weighted optimal start of the winter season during the first half of December (respectively 6 December) and a weighted optimal end of the winter season during the second half of March (respectively 28 March) (Fig. 6).

5 Conclusions

This study presents a GIS-based multi criteria approach to define the seasonality in the water logistic system of 20 municipalities in the Kitzbueheler region in the Austrian Alps. The fundamental geodatasets for this analysis are a mean snow cover start date raster and a mean snow cover end date raster. This method aims to determine an optimal winter and summer period, taking into account different water demand stakeholders, alpine hydrology and the characteristic present day water supply systems of the Alps. As the alpine winter is the period with the lowest availability in water resources and a period with high water demand, its temporal definition in order to analyse a regional water balance is an important issue.

Tourism and snow-making were defined as the two most important seasonal water demand stakeholders. Tourism was quantified in the number of overnight stays, and accounted for an annual water demand of 1.5 Mio. m^3, connected to the water supply systems of the municipalities in the region. Not connected to the public system is the water demand for snowing which accounts for an annual demand of 2.3 Mio. m^3. This number is calculated based upon the area of ski slopes with snow-making. The GIS-analysis of the seasonality of both stakeholders, gave a rather similar result. An optimal start of the winter season was defined during the first half of December; an optimal end of the winter season was stretched over the time interval between the 16th of March and the 15 April. A weighted analysis of these results, defined the beginning of December and the End of March as the key dates for differentiating between winter and summer in the alpine logistic system of the study area. For practical reasons, it can be stated that the winter months are December to March, and the summer months April to November.

This study resulted in a specific differentiation of a winter and summer period for the purpose of analysing a water balance in an alpine environment on a regional basis. The rather small difference of the two main seasonal stakeholders is a result of the characteristics of the study area. Most ski regions have their ski runs reaching the valleys, and the municipalities are largely provided with water from springs located at elevations not much higher than the settlements they serve. In other alpine regions, with a larger variability in topography or hydrogeology, or with large ski regions located in high altitudes, this seasonality analysis could provide significant different results.

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Table 1. Basic data of the 20 municipalities in the Kitzbueheler region for the year 2001.

municipality	area (km^2)	inhabitants	overnight stays	overnight stays per inhabitant	public drinking water supply (%)	
					spring water (%)	groundwater (%)
Aurach	54	1203	70 773	59	80	20
Brixen	31	2574	251 173	98	100	0
Fieberbrunn	76	4180	422 983	101	100	0
Going	21	1730	306 132	177	100	0
Hochfilzen	33	1109	48 620	44	100	0
Hopfgarten	166	5266	337 044	64	95	5
Itter	10	1060	74 202	70	100	0
Jochberg	88	1540	63 938	42	100	0
Kirchberg	98	4958	861 551	174	80	20
Kirchdorf	114	3490	334 221	96	80	20
Kitzbuehel	58	8571	767 259	90	80	20
Oberndorf	18	1944	190 349	98	40	60
Reith	16	1595	114 056	72	0	100
St.Jakob	10	635	82 591	130	20	80
St.Johann	59	7959	517 857	65	80	20
Westendorf	95	3454	418 244	121	100	0
Bad Haering	9	2265	149 975	66	70	30
Ellmau	36	2524	662 712	263	100	0
Scheffau	31	1211	246 248	203	100	0
Soell	46	3364	449 624	134	80	20
total	1070	60632	6 369 552	105	80	20

Table 2. Total water demand for the 20 municipalities in the Kitzbueheler region.

definition	yearly water demand in million m^3	Water sources
Public base water demand	3.5	springs (80%) and ground water (20%) feeding the public water infrastructure
Public seasonal water demand	1.5	
Seasonal snow-making water demand	2.3	springs, groundwater and surface water, not attached to the public water infrastructure

Table 3. Weighted seasonality results, expresses in values relative to "1" for half month periods, and in an absolute date.

	snow-making	tourism	water logistic system
mean snow cover start date (SCOV6190_S)			
16 to 30 November	0.03	0.50	0.22
1 to 15 December	0.88	0.48	0.72
16 to 31 December	0.09	0	0.06
Interpolated day	9 December	1 December	6 December
mean snow cover end date (SCOV6190_E)			
1 to 15 March	0.15	0	0.09
16 to 31 March	0.73	0.23	0.53
1 to 15 April	0.09	0.73	0.34
16 to 30 April	0.03	0.05	0.04
Interpolated day	23 March	5 April	28 March

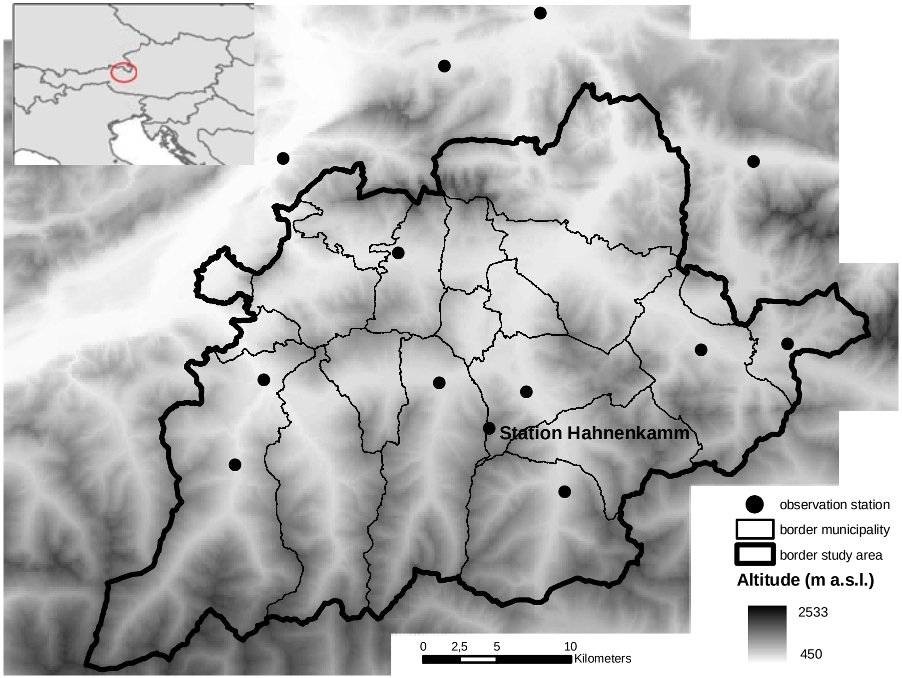

Fig. 1. Topography and snow observation stations in the study area Kitzbueheler Region, Province of Tyrol, Austrian Alps.

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Seasonality in the alpine water logistic system

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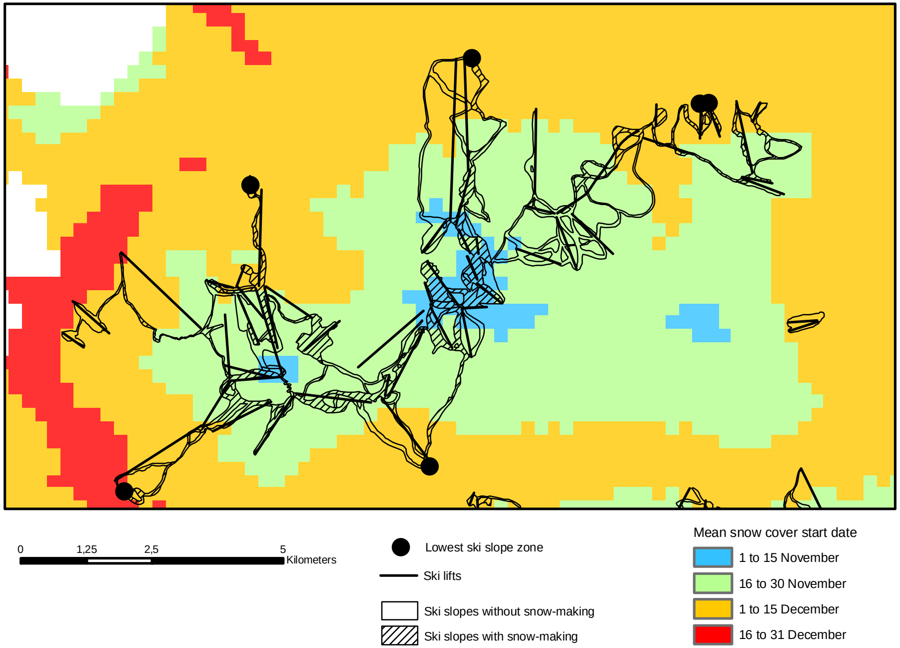

Fig. 2. Location of a number of ski regions in the study area, with indication of ski slopes with snow-making and their lowest topographic zone.

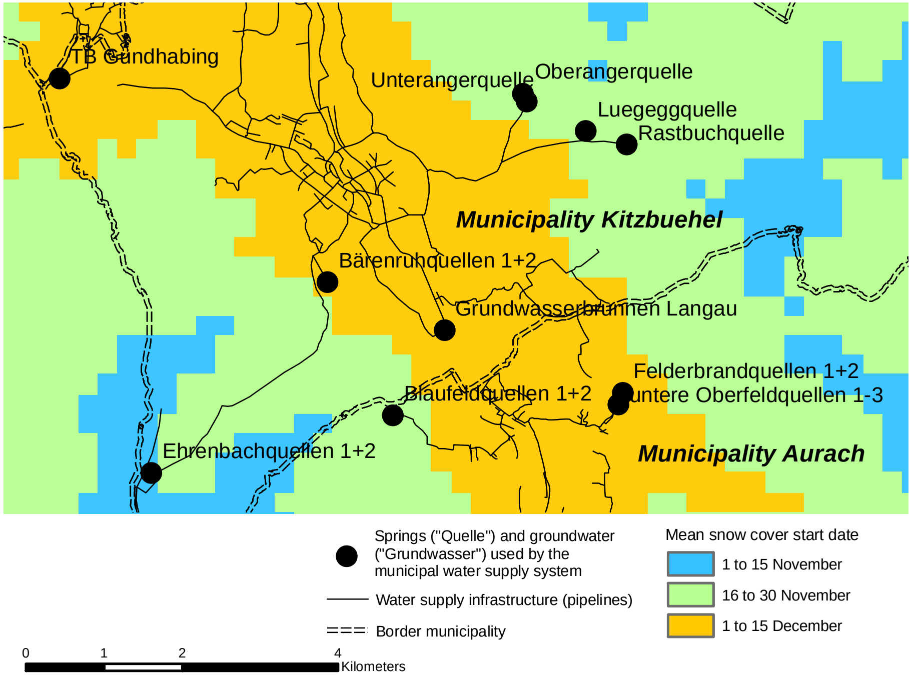

Fig. 3. Schematization of parts of the infrastructure (water pipe distribution network, springs and groundwater wells) of the public water supply systems of the municipalities Kitzbuehel and Aurach.

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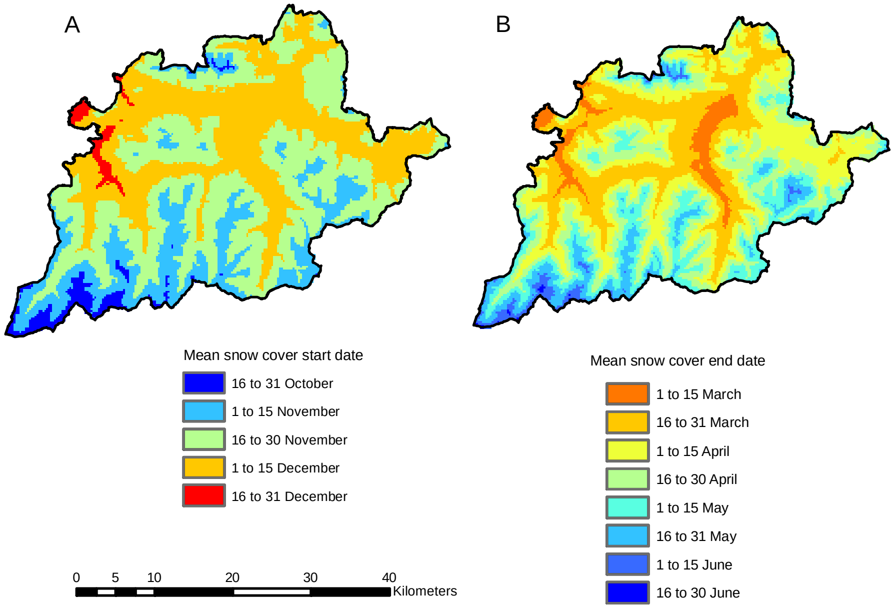

Fig. 4. Interpolated raster datasets (resolution 250 m×250 m) mean snow cover start date (SCOV6190_S) **(A)** and mean snow cover end date (SCOV6190_E) **(B)** for the World Meteorological Organization's climate normal period from 1961 to 1990.

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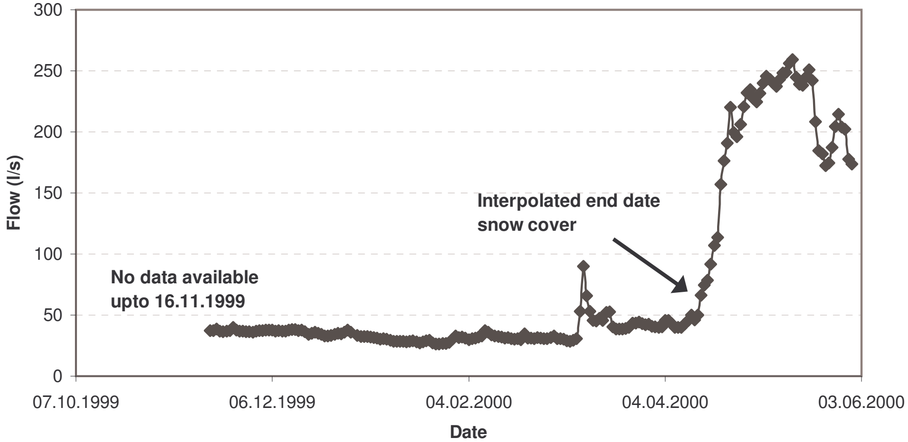

Fig. 5. Relationship between the spring "Schreiende Brunnen" (995 m a.s.l.), located in the municipality of Fieberbrunn, and the interpolated snow cover end date for the winter 1999-2000 (15 April).

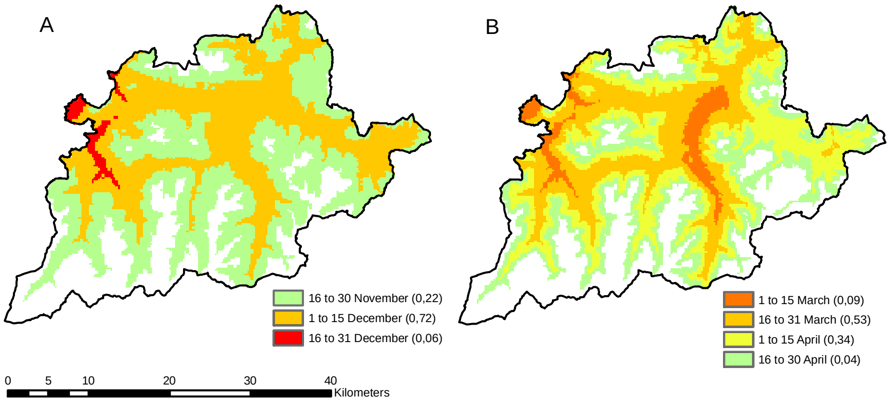

Fig. 6. Weighted optimal start of the winter season **(A)** and weighted optimal end of the winter season **(B)** for the water logistic system of the study area Kitzbueheler region, as the result of equation (3). The weighted values (between brackets) are relative to the number 1.