Hydrol. Earth Syst. Sci., 12, 91–100, 2008
www.hydrol-earth-syst-sci.net/12/91/2008/

Hydrology and Earth System Sciences

Technical Note: Seasonality in alpine water resources management – a regional assessment

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Received: 17 August 2007 – Published in Hydrol. Earth Syst. Sci. Discuss.: 28 August 2007
Revised: 22 November 2007 – Accepted: 18 December 2007 – Published: 25 January 2008

Abstract. Alpine regions are particularly affected by seasonal variations in water demand and water availability. Especially the winter period is critical from an operational point of view, as being characterised by high water demands due to tourism and low water availability due to the temporal storage of precipitation as snow and ice. The clear definition of summer and winter periods is thus an essential prerequisite for water resource management in alpine regions. This paper presents a GIS-based multi criteria method to determine the winter season. A snow cover duration dataset serves as basis for this analysis. Different water demand stakeholders, the alpine hydrology and the present day water supply infrastructure are taken into account. 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 different geographical datasets winter was defined as the period from December to March, and summer as the period from April to November. By determining potential regional water balance deficits or surpluses in the present day situation and in future, important management decisions such as water storage and allocation can be made and transposed to the local level.

1 Introduction

1.1 Seasonality in alpine water resources management

Integrated management of water resources requires to balance water utilisation from various stakeholders against available resources at the catchment level (Frederick, 1997). In case of constant demand and resources such an assessment can be made easily on the basis of an annual water balance. However, typically both the water utilisation and the available resources are fluctuating over time, with cyclic variations on a daily, weekly and seasonal basis. The integrated management of water resources has to take these temporal variations into account and water mass balances have to be made over the relevant periods.

Alpine areas are particularly affected by seasonal variations, that is by differences between the summer and the winter period. Reason is that both the natural hydrology as well as the demand differs significantly during winter. First the availability of water resources (both surface and spring water) is generally lowest during this period due to the storage of water in form of snow and ice. On the other hand this period of minimal water availability is met by the peak water demand from stakeholders, due to winter tourism and water demand for technical snow production. The effect of climate change is contributing further to this problem as mountainous areas are particularly vulnerable to temperature and precipitation changes (Beniston, 2003).

Based on the above it is clear that a water balance analysis in alpine catchments must be performed at least on the seasonal level. A clear distinction between summer and winter periods is thus a must for any integrated assessment. Until now seasonality has been addressed in the literature not generic, but only with specific focus and for specific locations. E.g. Tappeiner et al. (2001) defined the winter season for the alpine upper Passeier Valley in Italy from November to May. Christensen and Lettenmaier (2007) defined winter from October to March, and summer from April to September.

The aim of this paper is a generic approach to define the winter season in an alpine catchment from the point of view of an integrated assessment of water resources.

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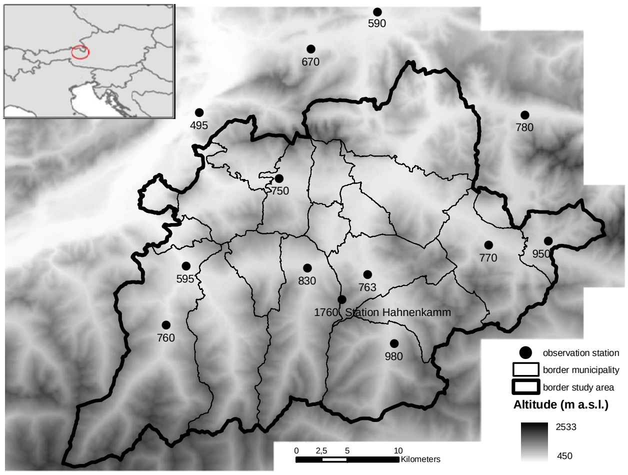

Fig. 1. Topography and snow observation stations (with indication of elevation) in the study area Kitzbueheler Region, Province of Tyrol, Austrian Alps.

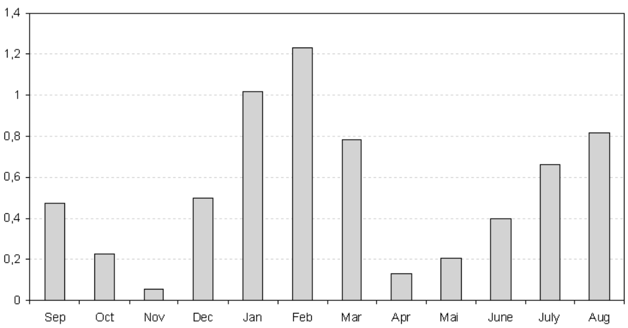

Fig. 2. Average monthly number of tourist overnight stays (in Mio.) recorded for the years 2000 to 2006 in the Kitzbueheler region.

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 (Schoenback et al., 2004). 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 rare.

1.3 Water resources

The seasonality of hydrological elements in alpine regions is highly dependent on altitude (Merz and Bloeschl, 2003). Jansson et al. (2003) stated that snow and ice significantly affect catchment hydrology by temporarily storing and releasing water. 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. Schoener and Mohnl (2003) state that the duration of snow cover influences the ground water recharge. The availability of alpine water resources is therefore generally lowest in winter, the period where typically low flows occur. Lahaa and Bloeschl (2006) divided Austria into an alpine region with low flows dominated by winter processes and into flatlands and hilly terrain with low flows dominated by summer processes.

1.4 Water demand

Winter tourism is one of the most important industries in the Alps (Elsasser and Messerli, 2001). 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. In recent years, the production of technical snow has become an important issue in most ski areas of the world and is likely to increase due to climate change (OECD, 2007). Water, air, energy and temperatures below freezing are required to produce technical snow.

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. According to the land use dataset of CORINE only 2.5% of the study area is urbanised (Table 1). There are no glaciers in the area. 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 (Fig. 2). The total population (principal residence) of the region is 60 632 inhabitants (Table 2). 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

3.1 Base and seasonal water demand

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. 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. 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 3), 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 an annual basis, and secondly a seasonal water demand (30%), which depends on the number and the temporal distribution of overnight stays. Of the base water demand of 3.5 million m^3, population attributes to about 80% of this value. Although assumed constant, the base water is still to be included in the seasonality analysis, due to the seasonal behaviour of the water resources providing the water supply systems.

Apart of the public water demand (with its both constant and seasonal shares), technical snow production is to be regarded as second seasonal water demand factor. Proebstl (2006) evaluated the water demand for snowing in different Bavarian and Tyrolean ski regions in similar altitudes as the project area of this study. In terms of temporal water demand it is to be differentiated between base snowing at the beginning of the winter season and improvement snowing during the remaining winter season. As a ground rule it is stated that 2.4 m^3 of snow is generated from 1 m^3 of water. For base snowing, a snow height of 20 to 35 cm is required (70 to 120 l water pro m^2). For improvement snowing 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 3).

Table 1. Land use in the Kitzbueheler region.

Description	Percentage of total area
Urbanised areas	2.5
Broad-leaved and mixed forest	19.1
Coniferous forest	30.9
Natural grassland (predominately alpine meadows)	25.8
Pastures (predominately located in the valleys)	17.9
Crops	0.1
Sparsely vegetated areas	2.3
Bare rock	1.3
Water bodies	0.1

3.2 Snow cover start and end date

The fundamental dataset for the seasonality analysis is a snow cover duration map of the area. Reason being that all three water demands (base water demand, water demand for tourism/overnight stays, technical snow production) are affected by the snow cover. The relation is obvious for technical snow production and also for winter tourism (as snow coverage is fundamental for winter sports). The base water demand is affected indirectly as snow cover indicates that availability of water resources decreases.

The snow cover duration map 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. 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 resolution) for the entire Austrian area, based upon a spatial interpolation of daily snow depth measurements at 835 climatological stations for the WMO'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. A correction of the resulting snow cover was made taking into account exposition and slope. 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). In Alpine regions the duration of winter cover is essentially shorter than snow cover, as occasional snow cover days are likely to occur in autumn or spring.

The analysis for the Kitzbueheler study area is based on the winter cover, but in the remaining text this term will be referred to as snow cover. 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 cover day is taken from Schoener and Mohnl (2003). Of these stations, 12 are located in the valleys at an altitude between 495 m

Table 2. 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 spring water (%)	water supply (%) 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	60 632	6 369 552	105	80	20

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 (Bucher et al., 2004). In the same way a spatial interpolation of the mean start and 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 (250m resolution) are a mean snow cover duration and a mean snow cover start date (SCOV6190_S) and end date (SCOV6190_E) raster. The latter 2 geodatasets, which comprise daily information, are used in the seasonality analysis.

3.3 GIS-multicriteria method

For computing the seasonality in alpine water resources management, a GIS-multicriteria approach is chosen to make it possible to account for on the one hand the base water demand and on the other hand 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). Multicriteria decision analysis using GIS applies a set of weight factors to each data characteristic. In this study, the evaluation criteria for all three water demand factors are the snow cover start date (SCOV6190_S) and end date (SCOV6190_E rasters). Weight factors are applied in relation to the demand quantity.

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, as 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 with regard to the water demand stakeholder of snow-making. This assumption is a simplification, as in reality snow-making starts already before snow cover as soon as the temperature is sufficiently low. How much earlier a ski operator starts snow-making depends on the one hand on climatic factors and on the other hand on the legislation regarding the start date. However, 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 tend to differ among ski-regions of the Kitzbueheler study area – even with their slope base at similar altitudes. The choice of the start of the snow cover as a conservative indicator for temperatures below zero can therefore imply a

Table 3. 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

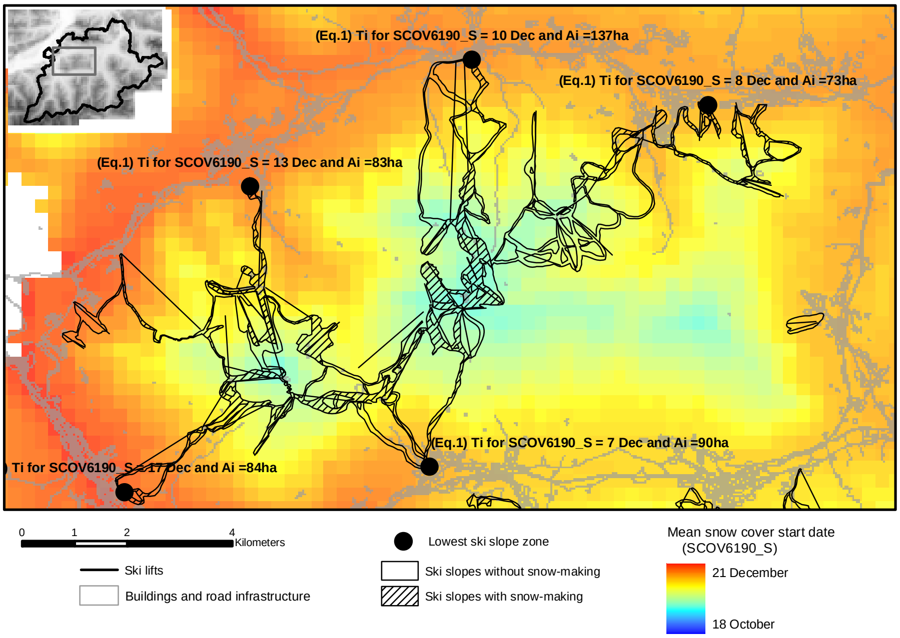

Fig. 3. Location of the interconnected ski region "skiwelt Wilder Kaiser-Brixental" in the study area, with indication of ski slopes with snow-making and their lowest topographic zone. The values for T_i and A_i in Eq. (1) for the mean snow cover start date raster (SCOV6190_S) are given.

shortening of the realistic snow-making season. On the other hand, snow-making is likely to stop before the end of the snow cover in spring, as snow cover usually persists for some time under melting conditions – when snow making is not possible anymore. 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. Because the decisive zone of the ski slope for the seasonality analysis is the lowest zone, this area is selected for the analysis. This GIS-based analysis is exemplarily visualised in Fig. 3 and summarised in the equation

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

where T_{snow} is the weighted day for all ski regions and T_i the selected day for a specific ski region i in the snow cover start date (SCOV6190_S) or end date (SCOV6190_E) raster. 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 analysis, the seasonal

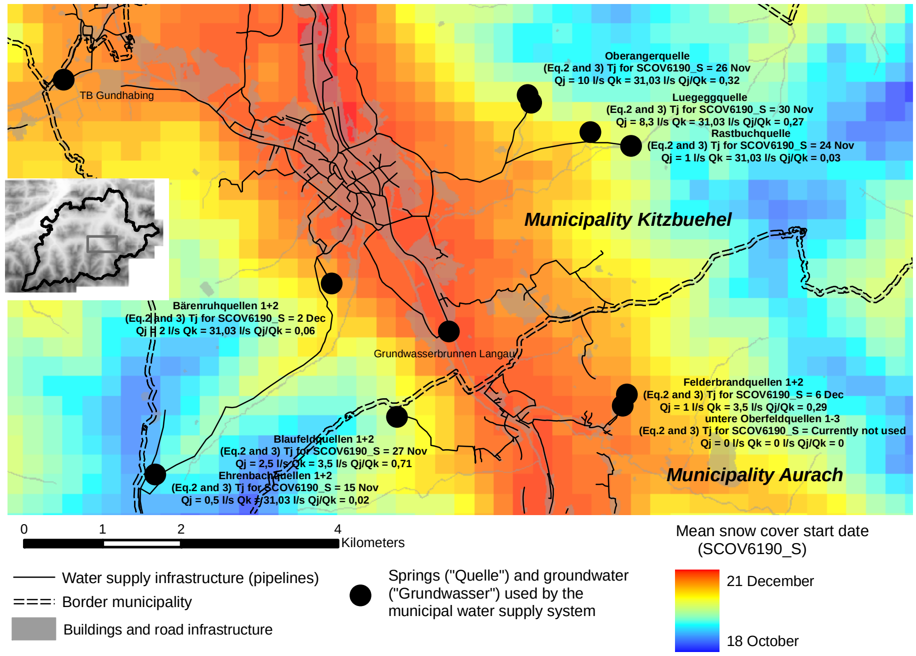

Fig. 4. Schematization of parts of the infrastructure (water pipe distribution network, springs and groundwater wells) of the public water supply systems of the municipalities Kitzbuehel and Aurach. The values for T_j, Q_j, Q_k and Q_j/Q_k in Eq. (2) and Eq. (3) for the mean snow cover start date raster (SCOV6190_S) are given. For Eq. (2) O_k is about ten times higher for the municipality of Kitzbuehel compared to Aurach, resulting in a larger impact on T_{tour}. For Eq. (3) I_k is about seven times higher for the municipality of Kitzbuehel compared to Aurach, resulting in a larger impact on T_{base}.

Table 4. Weighting factors in Eq. (4) for a winter season from December to March.

definition	water demand in million m^3 from December to March	D_{snow}, D_{tour} and D_{base} in Eq. (4)
Public base water demand	1.2	D_{base}=0.28
Public seasonal water demand	0.8	D_{tour}=0.19
Seasonal snow-making water demand	2.3	D_{snow}=0.53
Sum water demand stakeholders	4.3	

behaviour of the water resources providing the water supply systems to which hotels and guesthouses are connected, is assessed. As ground water resources are utilized to a minor extent (Table 3), only spring water resources are considered. 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 exemplarily visualised in Fig. 4 and summarised in the equation

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

where T_{tour} is the weighted day in the snow cover start date (SCOV6190_S) or end date (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 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 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 (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 (partly) served by spring water.

In order to evaluate the indirect impact of the base water demand on the seasonality, the seasonal behaviour of the water resources providing the water supply systems to which the population in the municipalities are connected, is assessed.

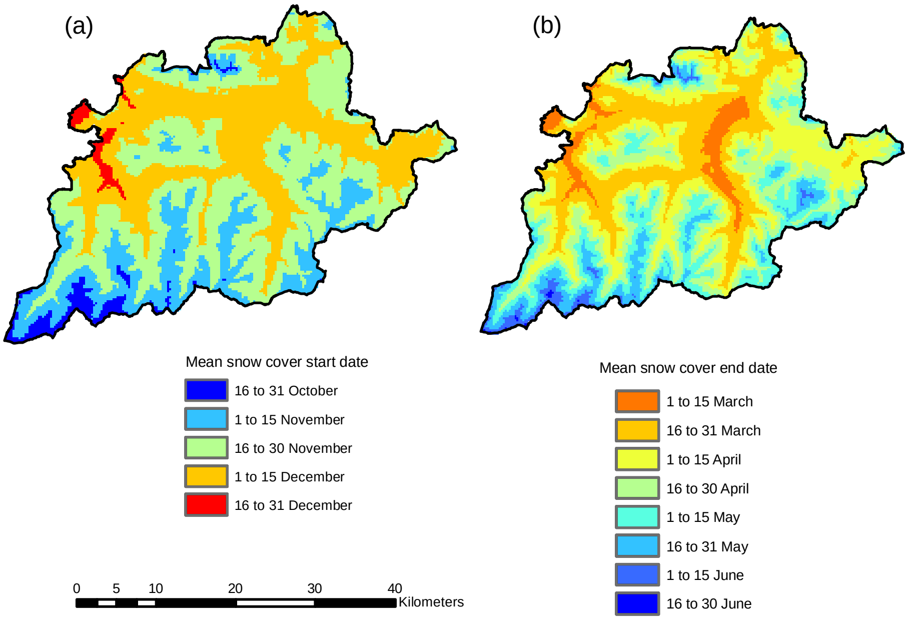

Fig. 5. Interpolated raster datasets (resolution 250 m×250 m) mean snow cover start date (SCOV6190_S) **(a)** and mean snow cover end date (SCOV6190_E) **(b)** for the World Meteorological Organization's climate normal period from 1961 to 1990.

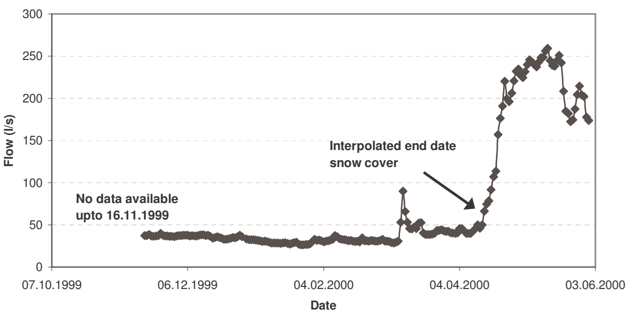

Fig. 6. Example of interaction between the hydrological regime (flow) of the spring "Schreiende Brunnen" (995 m a.s.l.), located in the municipality of Fieberbrunn, with the interpolated snow cover end date for the winter 1999–2000 (15 April).

This approach is similar to the approach for tourist overnight stays. Only population (Table 2) is taken into account, as it amounts for the largest proportion of base water demand in this area. The procedure is exemplarily visualised in Fig. 4 and summarised in the equation

$$T_{\text{base}} = \sum((\sum T_j(Q_j/Q_k))(I_k/I_{\text{base}})) \quad (3)$$

where T_{base} is the weighted day in the snow cover start date (SCOV6190_S) or end date (SCOV6190_E) raster for all public water supply systems that are (partly) served by spring water within the study area. $\sum T_j(Q_j/Q_k)$ represents the same factor as in Eq. (2). I_k represents the number of inhabitants connected to the water supply infrastructure for a specific municipality k (partly) served by spring water. I_{base} represents the number of inhabitants connected to the water supply infrastructure for all municipalities in the study area (partly) served by spring water.

Based upon the Eqs. (1), (2) and (3), the seasonality with regards to a water balance analysis for the study area can be analysed according to the equation

$$T_{\text{wbal}} = D_{\text{snow}}T_{\text{snow}} + D_{\text{tour}}T_{\text{tour}} + D_{\text{base}}T_{\text{base}} \quad (4)$$

where T_{wbal} is the weighted day in the snow cover start (SCOV6190_S) or end date (SCOV6190_E) raster. D_{snow}, D_{tour} and D_{base} represent respectively the relative amount of water demand of the seasonal stakeholder snow-making, tourism in the form of overnight stays and the base water demand in relation to the total water demand of all 3 assessed stakeholders. The definition of these amounts poses a problem for D_{tour} and D_{base}, as they have to be related to the winter season – which has not been defined yet and is only the result of Eq. (4). Therefore a first estimation of the winter season should be made. These values have then to be adapted iteratively, after analysing the results in Eq. (4). A good reference can be the seasonality in overnight stays (Fig. 2), in which a winter season from December to March can be identified. The weighting factors D_{snow}, D_{tour} and D_{base} for this first estimation of the winter season are 0.53, 0.19 and 0.28 respectively (Table 4).

4 Results

The interpolated mean snow cover duration raster (SCOV6190) is characterised by a minimum (respectively

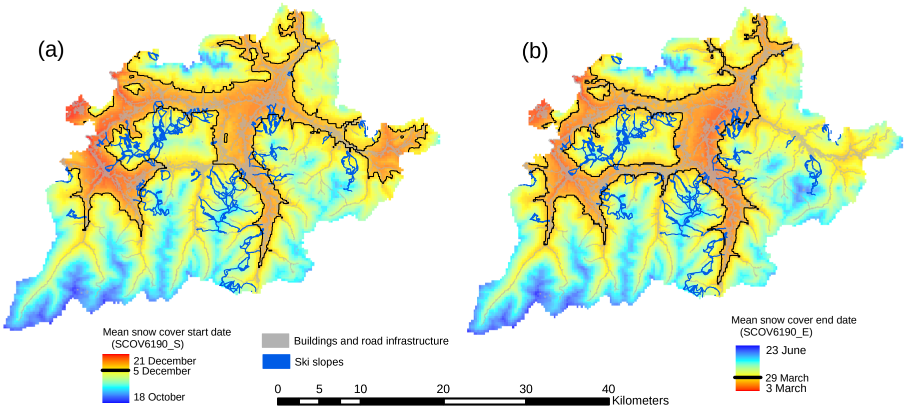

Fig. 7. Weighted start of the winter season 5 December **(a)** and weighted end of the winter season 29 March **(b)** for the study area Kitzbueheler region, as the result of Eq. (4).

Table 5. Weighted seasonality results (daily time step).

	mean snow cover start date (SCOV6190_S)	mean snow cover end date (SCOV6190_E)
snow-making	9 December	23 March
tourism	1 December	5 April
base water demand	1 December	5 April
water resources management – water balance analysis	5 December	29 March

maximum) of 7.4 days (respectively 8.7 days) lengthening with every 100 m increase in elevation. This raster was verified with the mean snow cover duration raster (both raster period 1961 to 1990 and resolution 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. 5) have been interpolated on a daily basis (i.e. every grid cell defines a specific day of the year). In Fig. 5 they are categorised in half-monthly intervals, in order to show the much shorter temporal and spatial variation of the snow cover start date raster (SCOV6190_S) (2.5 months from mid October to the end of December) in comparison to its counterpart end date (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. 6 shows the interaction between the spring "Schreiende Brunnen" and the interpolated snow cover end date for the winter 1999–2000 (15 April), a raster 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 results in the 9 December as start and the 23 March as end of the winter season (Table 5). The GIS-analysis of Eq. (2) for the water demand stakeholder tourism results in a weighted start of the winter season on the 1st of December, and a weighted end of the winter season on the 5 April. The GIS-analysis of Eq. (3) for the stakeholder base water demand (in the form of inhabitants) gives the same results. The analysis of Eq. (4) defines a weighted start of the winter season on the 5th of December and a weighted end of the winter season on the 29 March (Fig. 7). This start date of the winter season varies from an elevation of approximately 700 m to 1000 m, depending on the local snow conditions within the area. In accordance the end date varies from an elevation of approximately 700 m to 1150 m. As the resulting winter period (December to March) is the same as the assumed winter period for estimating the weighting factors D_{snow}, D_{tour} and D_{base}, these factors do not have to be redefined.

5 Conclusions

This study presents a GIS-based multi criteria approach to define a winter and summer season with respect to the analysis of a water balance between available water resources and water demand 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.

Public base water demand (3.5 Mio. m^3 on a yearly basis) has to be taken into account in such analysis although being a constant demand. 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 technical snow production which accounts for an annual demand of 2.3 Mio. m^3. The GIS-analysis of the seasonality of these three stakeholders in the case study gives a rather similar result. This is due to the characteristics of the study area, where most ski regions have their ski slopes reaching the valleys, and the municipalities are provided to a significant extent with water from resources located close to the valleys. A weighted analysis results in the 5 December and the 29 March as key dates for differentiating between winter and summer. For practical reasons, it can be stated that the winter months are December to March, and the summer months April to November.

As stated in the methodology, this approach simplifies the definition of the actual seasonal water demand period regarding snow-making. However, other approaches taking into account frost days – or better hours – or a snow model are definitely more complex and still to be regarded with caution, as the actual first snowing date is dependent on local legislation. The start of the snowing season is notwithstanding very important, as base snowing accounts for 40% of water volumes. Although the study area currently does not have a regional water management plan for the present and future situation, a total reservoir volume - divided over about 20 reservoirs - of 0.9 Mio. m^3 for snowmaking water storage is installed in the region, capable of providing the total base water demand in the current situation (40% of 2.3 Mio. m^3).

With the definition of a winter period of four months for the study area, it is expected that the presented methodology will define longer winter periods for many alpine regions that are located at higher elevations and in similar climate regions. This methodology can also result in a significant different seasonality for alpine regions with a larger variability in topography or hydrogeology, or in different climate zones.

This methodology also provides the possibility to define seasonality for water resource management for future conditions. Breiling and Charamza (1999), for example, forecast an increase of the snowline of 100 m in the Kitzbueheler region. An analysis of the seasonality will probably result in a shortening of the winter period, due to the upward shift of the snowline (the lowest zone of ski slopes in Eq. (1) will shift upwards). This means that a water balance (water resources – water demand) for the winter period will be analysed over a shorter period of time compared with the existing situation. Another implication of climate change can be a rise in the area with snowmaking facilities and a resulting increase in water demand (OECD, 2007), implying different weighting factors D_{snow}, D_{tour} and D_{base} in Eq. (4). A shift in overnight stays from regions with low snow reliability to higher regions (OECD, 2007) is accounted for in the Eqs. (2) and (4). Population increase (or decrease respectively) will have an effect on the seasonality due to different values in Eqs. (3) and (4).

It is to be noted that the relationship between overnight stays and inhabitants is an important issue in this methodology. The Kitzbueheler region shows an average of 105 overnight stays per inhabitant (Table 2). In contrast the ski region of Soelden has recorded a total number of 2.1 Mio. overnight stays for a population of 3128 resulting to 676 overnight stays per inhabitant. The city of Innsbruck on the other hand records 1.2 Mio. overnight stays in 2006 with a population of 117 000 which results to 10 overnight stays per inhabitant. In case such a large city is incorporated in the presented seasonality analysis of a certain region, its impact will be significant due to its base water demand in the Eqs. (3) and (4).

Acknowledgements. The authors would like to express their gratitude to all members of the project team of the Waterpool Competence Network (http://www.waterpool.org) for the support of this work.

Edited by: A. Montanari

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