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Determination of Snow Water Equivalent (SWE) According to Elevation and Its Importance for Water Resources in Semi-Humid Region of Turkey

Turan Yüksek[1], Ayse Yavuz Özalp[2] , Mehmet Özalp[2], Filiz Yüksek[3], and Esin Erdoğan Yüksel[4]

[1]Assoc. Prof., Recep Tayyip Erdoğan University, Rize, Turkey; [2]Assist. Prof., Artvin Çoruh University, Artvin, Turkey; [3]Engineer, Pazar Forestry Directorate, Rize, Turkey; [4]Res. Asst., Artvin Çoruh University, Artvin, Turkey.
E-Mail: filiz6153@yahoo.com

Abstract :

The aim of this study was to determine the altitudinal distribution of snow water equivalent (SWE) in the north-east facing aspect of the basin of the Fabrika River in Artvin. Study sites were selected at four different altitudes, where a total of thirty snow samples were collected from each study site from the depth steps of 0–5 cm and 5–10 cm. As a result, the snow sample collected on February 21, 2008 at 1250 m altitude and from 5–10 cm depth was found to produce the highest SWE value while the snow sample collected on February 15, 2008 at 200 m altitude and from 0–5 cm depth was found to produce the lowest SWE value. A strong relationship was detected between the SWE of the snow sample collected from 0–5 cm depth and the altitude of the sampling site. This relationship was formulated as: [$R^2= 0.94$, $SWE = 0.1328 * (Altitude^{0.687})$], *while this relationship was formulated as:* $R^2= 0.928$, $SWE = 0.15 * (Altitude^{0.6750})$], *in depth of 5–10 cm.*

Key Terms: Snow water equivalent; Snow accumulation; Semi humid region; GIS, Elevation

Introduction:

Artvin province is one the most mountainous regions in Turkey. Topography and climate vary significantly from the north to the south of the province. The northern part of Artvin faces the coast and is relatively flat. The rivers in this part of Artvin are mainly fed by rain water while the rivers in the southern part of the city are mainly fed by melting snow. Coruh River -known as the fastest flowing river in Turkey- is the main river that flows throughout the city centre and that plays a major role in shaping the regional topography. Annual precipitation decreases significantly from north to south, while the effects of drought increase. The assessment of water resources provided by snowfall is very important in snow-fed basins of Artvin Province. Snow Water Equivalent (SWE), usually expressed as a volume per unit area (e.g. in mm; ml/100cm3), is used to quantify the water resources stored in snow. In principle, to assess the annual amount of water resources in snow form, a SWE estimate should be made for each snowfall. This requires measurement of snow depth and density (Bohr and Aguado 2001; Elder et al. 1991).

Unfortunately, snow density measurements are time consuming, uncommon and potentially hazardous, particularly in complex terrains and during the accumulation season (Elder et al. 1991). Often, the estimated SWE stored in the snowpack at the end of the winter season, is used as a rough estimate of the annual accumulated SWE. This is dependent on the altitude but is commonly estimated around April 1st 20 (Ranzi et al. 1999; Bohr and Aguado 2001). Snow accumulation and melt at high altitudes have a significant influence on hydrological processes, forest ecosystems, grasslands and agricultural activities in Artvin. Precipitation stored in snowpack during the winter is released as snow-melt during a relatively brief period in spring, which typically gives rise to annual maximum stream flows (Koivusalo and Kokkonen 2002). Melting snow can contribute to major flood events; augments early summer base flows (Warren 1985); and can significantly influence the chemical and ecological characteristics of streams (Davies et al. 1993). There is no previous long-term systematic study on the snowpack accumulation and melt in the study area; and the varied influences of winter snowpack on the hydrology of individual catchments are poorly understood. It has been established that the amount and continuity of snow vary greatly from one year to another, depending on the location (Knuth 2007). Each year, data from snow surveys are used to predict the effects of snow accumulation and melt on transportation networks, recreational opportunities, length of winter logging seasons, flood hazards, reservoir management and water supplies (Winkler and Roach 2005). The importance of snow water quivalent (SWE) has been a concern in developed countries for more than 30 years and a lot of research has been done to quantify the effect of of SWE on water flood, irrigation and ground water.

A large part of the Artvin region has semi humid climate condition. Snow cover is important for several reasons in semi-humid part of Artvin, Turkey. First, it represents a major storage of water, which is released during the spring-melt period. Knowledge of how much water is contained in snow cover (the snow water equivalent, or SWE) and the rate at which it melts is critical information for flood forecasting, agriculture and optimal management of water resources. Therefore, the amount of winter snow has great importance in these areas to maintaining a healthy ecosystem of life.

There are a lot of researches about the effect of the effect of of SWE on water flood, irrigation and ground water in many part of the world; however, the studies done about this subject in Turkey are insufficient. However, the study area has no research station to provide observations and measurements of the amount, seasonal distribution and melting status of the snow falling within this region. To date, relatively few studies has been conducted of snowfall in Artvin Province.

The present study determined (i) the altitude-related and depth-related changes in SWE values within the watershed of the Fabrika River at different times (February 15 and 21, 2008); (ii) snow depth according to altitude and (iii) depth-related (0–100 cm depth) changes in SWE of the snow accumulated within the Kafkasor location.

Materials and Methods

Description of The Study Area:

This study was conducted on an east-west oriented ridge on the northern boundary of the Artvin-Fabrika watershed (AFW). The ridge is typical of slope morphologies within the AWF (Figure 1). The study area is located at latitude 41° 09' 53''- 41° 10' 04'' and longitude 41°47' - 52''- 41° 15 49' 56 (Table 1). The elevation of the ridge ranges from 200 m to 1250 m. The mean gradients on the north and south-facing slopes are 0-15 and 15- 30 degrees, respectively (Figure 1-a). The study area is located on dacite and riodacite bedrocks (Yılmaz et al. 1998).

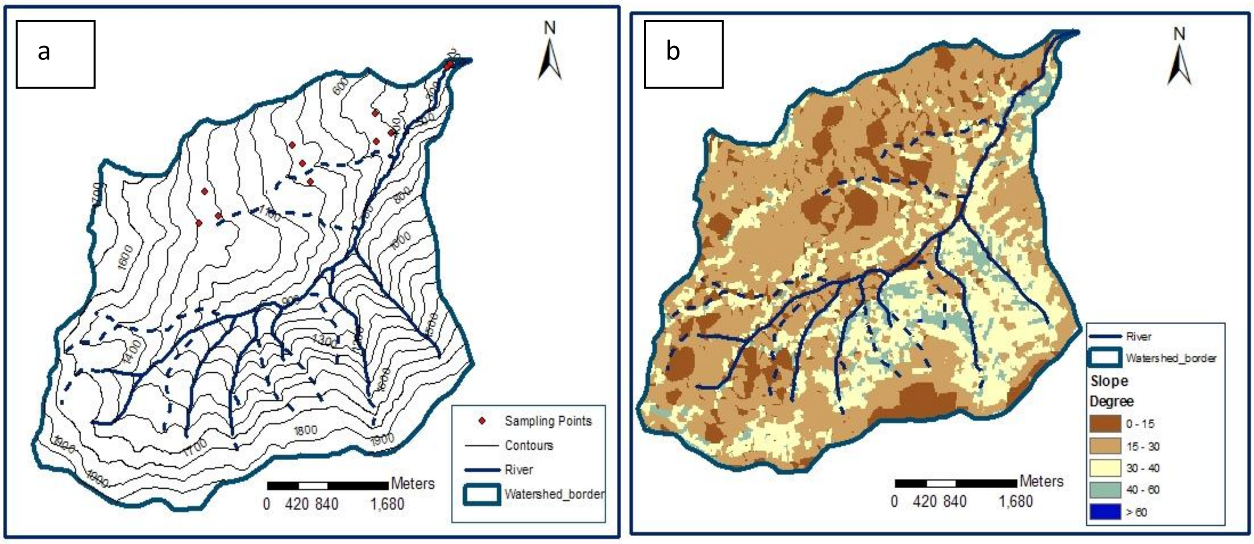

Figure 1. Snow samples collected from study sites (a) Slope degree (b), in the Artvin Fabrika Watershed.

The study area has a semi-humid Black Sea climate. The average annual rainfall is 689 mm, with the lowest rainfall recorded in spring (209.9 mm) and the highest rainfall in winter (337.7 mm) (Yuksek et al. 2008). The mean annual daily temperature is 12.3 °C (recorded in Artvin Meteorological Station at 575 m) (Yuksek et al. 2010). The mean annual number of snowy days in Artvin Province is 34 and the mean annual number of snowcapped days is 55, where snowfall is observed during the period between 20 December and 5 March (Anonymous 2008). Snowfall between altitudes of 200–1000 m generally melts relatively quickly. However, snowfall between altitudes of 1000–2200 m can remain until early June. Warmer air temperatures at the beginning of April initiate snow-melt, which increases the flow of the Fabrika and Coruh Rivers. Peak flows occur at the end of May and the beginning of June. For example, the mean daily flow of the Coruh River is 200 m^3s^{-1}, though discharge ranges between 38 m^3s^{-1} and 790 m^3s^{-1} at base flows to over 2431 m^3s^{-1} in major flood events (Sucu 2008). The annual flow regime usually reflects the 3 influence of snowmelt and has a marked alpine character, with a distinct period of high 4 flows occurring in late winter/early spring.

Table 1. Site locations, altitude, vegetation types and snow depth (cm) of the study area at each sampling date.

Location	Altitude	Vegetation type	Sampling Date	Mean Snow Depth (cm)
			15 Feb. 2008	15
Korzul	190±10	Grassland	21 Feb. 2008	16
			15 Feb. 2008	32
Gökorman	510±10	Grassland	21 Feb. 2008	40
			15 Feb. 2008	60
Katravan	870±10	Grassland in forest gap	21 Feb. 2008	75
Kafkasör	1240±10	Grassland in forest gap	15 Feb. 2008	105
			21 Feb. 2008	120

Sampling of Snow:

A preparatory study was carried out on the slope between Korzul and Kafkasor, to identify the location of meadows. These meadows were then classified into altitude steps and the locations of these steps were recorded using hand GPS. Three forms of data were collected at the study sites:

(1) Sampling according to altitude, depth and time: Three parallel, north-south transects were established at each study site. Each was 30 m long with a vertical spacing of 5 m (Figure 1-b). Snow samples were collected from each transect line at 0-5 cm and 5-10 cm depths and with 3-meter intervals, using a 100 cm3 cylinder. A total of 480 snow samples (3 transects × 10 sample points × 2 sampling depths × 4 altitudes × 2 sampling time) were collected on February 15 and 21, 2008.

(2) Snow depth sampling at altitude steps: Snow depth measurements (n=80) were made at 20 points randomly selected from the study sites. The locations of these points were recorded using hand GPS.

(3) Calculation of SWE values. Snow was collected from the Kafkasor study site (which was found to receive the highest snowfall of the study sites) on two different dates and at depths ranging from 0–100 cm.

Snow was sampled (to 100 cm depth) for 20 meters on the same transect line, with a 10 cm depth (from snow surface towards depths). 4 samples were collected from each depth step; A total of 240 snow samples were collected (10 depth steps x 4 samples x 3 sites x 2 sampling dates).

Determination of Snow Water Equivalent (SWE) and Snow Surface Model:

Snow samples were stored in plastic boxes (each box was 200 mm in size and had protective cover) and transferred to the laboratory in cartons. Snow samples were melted by adding 5ml hot water at 50°C. Samples were measured by using 10, 20 and 25 ml tape measures. The 5 ml of water used to thaw the samples was subtracted from each of the obtained values, to give the water equivalent of the snow samples (Anonymous 1982; Schmidlin 1990; Yuksek 2002). A snow surface model was mapped using the Kriging method in the ARC-MAP 9.2 Geographical Information System (GIS).

Statistical Analysis:

Statistical analysis was performed using analysis of variance (ANOVA) and, the mean values were subjected to the Duncan test ($P < 0.05$) to identify the main differences between the sites and between the two sampling dates for each site. SPSS statistical analysis software was used to identify potential correlation between variables. The mean values found for all variables are shown in relevant tables.

Results and Discussion:

The SWE of the snow samples collected from the study sites increased in parallel with the altitude steps. The highest SWE value was recorded in Kafkasor study site at the altitude of 1250 m while the lowest SWE value was recorded in Korzul study site at the altitude of 200 m. The lowest SWE value was recorded at the Korzul study site, which has an altitude of 200 m. Altitude-related differences recorded in the SWE values were found to be statistically significant (Tables 2a, 2b, 3a and 3b). The depth-related (0-5 and 5-10 cm depth) differences recorded in SWE values of the snow samples collected from the same study sites on different sampling dates (February 15 and 21, 2008) were found to be statistically insignificant.

Table 2a. Altitude-related changes in the SWE values of snow samples collected from 0- 5 cm depth on February 15, 2008.

Snow water equivalent	Snow Depth (cm)	Locations and altitudes (m)				F ratio	Sign. Level (P)
SWE	0-5	5.03^{d}	8.96^{c}	15.24^{b}	17.23^{a}	838.81	0.000

N= 30, SWE: Snow water equivalent (ml/100 cm^{3}), Values within a row followed by different small letters are significantly different ($P<0.05$).

Table 2b. Altitude-related changes in the SWE values of snow samples collected from 5- 10 cm depth on February 15, 2008.

Snow water equivalent	Snow Depth (cm)	Locations and altitudes (m)	F ratio	Sign. Level (P)

N= 30, SWE: Snow water equivalent (ml/100 cm^{3}), Values within a row followed by different small letters are significantly different ($P<0.05$).

Table 3a. Altitude-related changes in the SWE values (ml/1 100 cm3) of snow samples collected from 0–5 cm depth on February 21, 2008.

Snow water equivalent	Snow Depth (cm)	Locations and altitudes (m)				F ratio	Sign. Level (P)
SWE	0-5	5.21^{d}	9.36^{c}	15.52^{b}	17.32^{a}	799.45	0.000

N= 30, SWE: Snow water equivalent (ml/100 cm^{3}). Values within a row followed by different small letters are significantly different ($P<0.05$).

Table 3b. Altitude-related changes in the SWE values (ml/100 cm3) of snow samples collected from 5–10 cm depth on February 21, 2008.

Snow water equivalent	Snow Depth (cm)	Locations and altitudes (m)	F ratio	Sign. Level (P)

N= 30, SWE: Snow water equivalent (ml/100 cm^3). Values within a row followed by different small letters are significantly different (P<0.05).

Many previous studies have identified a linear relationship between snow water equivalent and altitude (Yuksek 2002; Dressler et al. 2006). Greater accumulation of snow and changes in the structure of the snowflakes at higher altitudes are suggested to affect snow water equivalent (Matzler 1993; Pulliainen 2006). The lower density of snow recorded at lower altitudes may be a factor in the low SWE values recorded at such altitudes. This may be the case for the Korzul and Gokorman study sites, both of which are located in the lower altitudes of the study area. The present study showed that the snow in these two locations was light and fluffy. Snow which is light and fluffy has lower water content than heavy snow. One other possibility might be the temperature within the clouds where the snow forms. Another possibility might be the temperature of the air through which the snow falls). Daily solar radiation and the maximum daily temperature of the study sites might also affect the SWE (Olson 2008). While the SWE values of the snow samples collected on February 15, 2008 showed a slight depth-related increase in Korzul, Gokorman and Kafkasor study sites, this increase was only statistically significant at the Katravan site (Table 4).

Table 4. Depth-related change in SWE values of snow samples collected on February 15, 2008.

Study sites	Sampling Depth (cm)		F ratio	Sign. Level (P)
	0-5	5-10		
Korzul	5.03	5.38	3.88	0.053
Gökorman	8.96	9.21	0.76	0.388
Katravan	15.24^b	16.13^a	5.72	0.020
Kafkasör	17.23	17.81	3.498	0.066

N= 30, SWE: Snow water equivalent (ml/100 cm^3), Values within a row followed by different small letters are significantly different (P<0.05).

In studies conducted in the northern hemisphere, (Stieglitz et al. 2001) found out that SWE values showed a statistically significant increase associated with depth. (Ozyuvacı 2001) concluded that density and SWE increased with greater depth. While the SWE of the snow samples collected on February 21, 2008 increased slightly with depth at the Gokorman and Kafkasorde study sites, this increase was statistically significant at the Korzul and Katravan sites (Table 5).

Table 5. Depth-related changes in the SWE values of snow samples collected on February 15, 2008.

Study site	Sampling Depth (cm)		F ratio	Sign. Level (P)
	0-5	5-10		
Korzul	5.21^b	5.69^a	5.90	0.041
Gökorman	9.36	9.71	0.88	0.415
Katravan	15.52^b	16.48^a	5.72	0.020
Kafkasör	17.32	17.95	0.910	0.066

N= 30, SWE: Snow water equivalent (ml/100 cm^3), Values within a row followed by different small letters are significantly different (P<0.05).

A strong relationship was found between the SWE values of 1 the snow samples and the altitude steps. This relationship formulated for the SWE values of the snow samples collected from 0-5 cm depth on February 15, 2008 is as follows:

$[R^2 = 0.94, SWE = 0.1328 * (A^{0.687})]$, [a]

This relationship is as follows for the SWE values of the snow samples collected from 5–10 cm depth:

$[R^2 = 0.928, SWE = 0.15 * (A^{0.6750})]$, [b]

Where; “R” refers to regression coefficient; “A” refers to Altitude; and “SWE” refers to Snow Water Equivalent. Snow depths measured on February 15, 2008 increased in parallel with the altitude steps. The altitude-related increase recorded in snow depths is formulated as follows:

$\text{Snow depth} = 10.28 + 0.015 * A + 0.000049 * A^2$ [c],

(“A” refers to altitude). This formula was used to calculate the snow depth change along the whole slope. A snow surface model was mapped using the Kriging method in the ARC-MAP 9.2 Geographical Information System (GIS) (Figure 3).

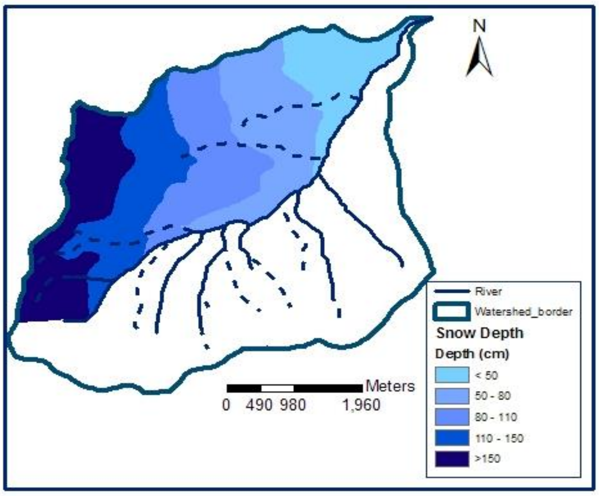

Figure 3. Altitude-related change in the snow depths along the same slope.

Martinec (2009) reported that snow density, snow hardness and water content of snow increase according to snow depth. As the thickness of the snow increased in Kafkasor, (the highest altitude study site), the SWE values increased linearly. As shown in Figure 4, the highest increase was recorded in the snow sample collected from 100 cm depth on February 21, 2008.

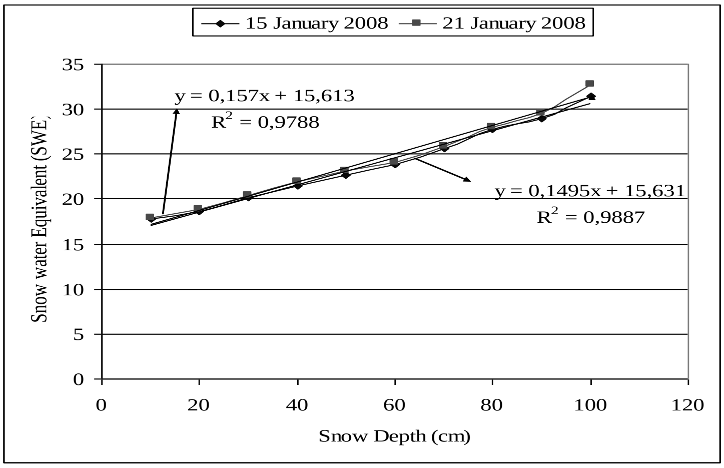

Figure 4. Depth-related changes in SWE values of samples collected from Kafkasor site on two different dates (February 15 and 21, 2008).

Conclusions and Recommendations:

The present study showed that SWE increased with increasing altitude and snow depth in the Fabrika Watershed in Artvin. The highest SWE was measured at 100 cm depth at an elevation of 1240±10 m at the Kafkasor site, while the lowest SWE was measured at 0-5 cm depth at an elevation of 190±10 m at the Korzul site. Analysis of Figure 3 indicates that there was a considerable increase in the depth 1 of snow-cover and SWE values at the higher-altitude sampling sites. Therefore, it can be concluded that the highest altitude slopes of the study area are of great importance in terms of SWE. Water depth, resulting from a total melt of snow cover or snow water equivalent (SWE), provides an indication of the quantity of water that will become available for use in the spring. The availability of water has implications for the agricultural sector and local ecosystems. SWE information is important to planners assessing snowmelt flood potential and to engineers designing structures to support snow weight. The SWE prior to the spring thaw, which is frequently the annual maximum SWE, is a key design parameter (Fassnacht et al. 2003). The uncertainty associated with future climate change means that effective management of natural resources, particularly water, has becoming increasingly important. The potential for increased water-stress in lowland settlements and agricultural areas means that snow water on slopes and at high altitudes will assume greater importance. Accurate snowfall and related data are the greatest importance for the Coruh River Basin, as it is predicted that many ecological factors within this basin (including micro-climate) will change in the long term due to the planned construction of 27 dam type and river-type hydroelectric power plants (2 of which have already been built). Therefore, more detailed studies should be conducted on issues related to SWE, snow accumulation and snow melt in Coruh basin, not only to ensure sustainable power generation in these hydro-electric plants, but also to monitor possible ecological changes. In addition, Snow Measurement and Observation Stations should be established, particularly within Artvin and other basins.

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