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Investigation of flow properties in natural streams using the entropy concept

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Abstract

This paper examines the discharge and velocity distributions in natural open channel flows using the entropy theory. Flow measurements were carried out at four different cross-sections in central Turkey. The mean and maximum velocities at these stations exhibited a linear distribution and the entropy parameter was calculated to be $M = 1.31$. Using this value, discharges for all flow conditions were calculated as a function of the measured maximum velocities (u_{max}). It was observed that the u_{max}/H and z_{max}/H ratios remained relatively constant when $0.2 \leq y/T \leq 0.8$, especially for the wider channels. Using these constant values for each station, u_{max} and z_{max} could be determined solely as a function of the water depth H. Although the calculated velocities were higher than those measured at some verticals, the entropy-based approach presents an attractive alternative to the traditional flow-measurement techniques for the determination of flow properties because of its simplicity and quick application.

Introduction

Determinations of flow discharge and velocity distributions over the open channel cross-section are very important for purposes such as water management, water supply, irrigation, flood control, etc. Velocity distributions are especially necessary for open-channel conditions in order to calculate important parameters such as shear stress distributions, energy loss, sediment discharge and turbidity. For this reason, the main objective of this study is to develop an easy velocity distribution model that provides suitable results based on a few parameters that are simple to measure or derive.

Flows in open channels and natural rivers are often described by the simplifying cross-section averaged one-dimensional hydraulic equations. In reality, river hydrodynamics is quite complicated because the river cross-sections and riverbeds are usually complex and do not meet the assumptions of a one-dimensional flow. For the purpose of determining the flow and hydraulic properties in rivers and streams, the conventional methods include the use of empirical formulas and velocity samples. Yet, their applications, especially in an unsteady nonuniform flow, are difficult because both the energy slope and the roughness characteristics tend to vary with time and water depth from one section to another along the flow direction, and also, measurement of velocity samples requires considerable time and effort.

Velocity distributions with fully developed, steady and uniform flows in open channels and flow over rough surfaces have been studied extensively by many researchers (Bayazit 1976; Kırkgöz 1989; Smart 1999; Ferro 2003; Ardiclioglu *et al.* 2005). There are well-known velocity distribution equations for open channel flows, such as the power law and the Prandtl–Von Karman universal velocity distribution law. Nevertheless, these two equations are invalid at or near the channel bed and are inaccurate near the water surface, where the maximum velocity occurs below the water surface. Therefore, these two equations cannot be used to solve the problems related to river flows.

Most recently, velocity distributions in open channels have been investigated using a probabilistic approach based on the entropy concept. Chiu (1988; 1989; 1991) proposed a probabilistic two-dimensional velocity distribution function based on the principle of maximum entropy, using an isovelline-based coordinate system and an entropy parameter M. The M value, which can be derived from the ratio of the mean and maximum velocities, is constant for flow in a channel cross section and is invariant with time and flow discharge (Chiu & Said 1995). Xia (1997) investigated the relationship between the mean and maximum velocities using data collected from several river cross sections on the Mississippi River and he found that the relationship was linear for all the river sections considered. Araújo & Chaudhry (1998) investigated the velocity distribution with measured longitudinal data and found that the entropy model performed better than the logarithmic model not only in general terms but also in all flow regions, especially those near the channel bed. Chiu & Tung (2002) studied the location of the maximum velocity as a function of M. Moramarco *et al.* (2004) developed a simple method for reconstructing the velocity profiles at a river section, which was based on the assumption that Chiu's velocity distribution can be applied locally. They showed that the shape of the observed velocity profiles for high flood events can be estimated with reasonable accuracy using their proposed simple approach.

Ardiclioglu *et al.* (2005) investigated the applicability of logarithmic and entropy-based velocity distribution equations for a rough-surface open-channel flow and suggested a new entropy parameter M. Their entropy equation leads to better agreement with measured data in all verticals and also near the bottom and free surfaces of the channel. Ardiclioglu *et al.* (2007), by comparing measured data, have shown that entropy-based velocity and shear-stress distribution equations can be successfully implemented in natural rivers. Ardiclioglu *et al.* (2008; 2010a, b), based on the field measurements, explored the applicability of various velocity distribution models defined by logarithmic law, power law and the entropy principle to natural rivers. In those studies, they used 10 different cross-sections and more than 30 different flow conditions. They found that the entropy concept can be applicable and easy for the determination of flow properties.

This study tested a simple and easy method for measuring discharge and velocity in natural streams using the entropy concept. Flow measurements were carried out using an acoustic Doppler velocimeter (ADV) in four different stream cross-sections in central Turkey. Entropy parameters M_i were investigated for each cross-section and a global M value was examined for all stations. For the entropy velocity distribution, the basic parameters of maximum velocity ($u_{\max}$) and its position ($z_{\max}$) were investigated in relation to an easily measurable parameter like water depth H. Furthermore, these relations were examined for the flow aspect ratio (water surface width, T/hydraulics radius, R).

Chiu's velocity distribution model

Well-known velocity distribution models like the logarithmic and power law cannot fully describe the velocity distribution, especially close to the solid boundary and free surface. An alternative to such a deterministic approach is the entropy method, which is based on the probability concept. Entropy methods are an alternative to conventional models that have been used in the past to predict equilibrium river profiles. The entropy of a system can be related to its energy production. Because entropy production is directly proportional to the energy production in a system, when energy is minimized, entropy production is also minimized. Entropy principles suggest that an open system where matter and energy can enter and exit the system will attain minimum entropy production at equilibrium (Chiu 1988).

Chiu (1988, 1989) investigated the flow properties using probabilistic approaches and proposed an entropy-based two-dimensional velocity distribution function for the simulation of the velocity field in river cross-sections. Chiu & Said (1995) indicated that an entropy parameter M reflects the equilibrium state of a channel section and it can be derived from pairs of maximum and mean velocities, $u_{\max}$ and U_{m}, measured at a channel section. The M value is a fundamental measure of information about the characteristics of the channel section. Chiu (1989) derived a two-dimensional velocity distribution in the following form:

$$u = \frac{u_{\max}}{M} \ln\left[1 + \left(e^M - 1\right) \frac{\xi - \xi_0}{\xi_{\max} - \xi_0}\right]. \quad (1)$$

In Eq. (1), the term $(\xi - \xi_0)/(\xi_{\max} - \xi_0)$ represents the cumulative probability distribution function in which $\xi(y, z)$ is the curvilinear coordinate associated with the isovels; $\xi = \xi_{\max}$ at the point where $u_{\max}$ occurs; $\xi = \xi_0$ at the channel bed where $u = 0$; and M is the entropy parameter. On the vertical z-axis, where the maximum velocity $u_{\max}$ occurs, ξ may be expressed as a function of z (Chiu & Said 1995):

$$\xi = \frac{z}{H - h} \exp\left(1 - \frac{z}{H - h}\right), \quad (2)$$

where z is the distance from the channel bed, H is the water depth and h is the distance from the surface to the point where maximum velocity occurs. When $u_{\max}$ occurs below the water surface, then $h > 0$. If $h \leq 0$, then $u_{\max}$ occurs at the water surface. The velocity distribution equation is then expressed as

$$u = \frac{u_{\max}}{M} \ln\left[1 + \left(e^M - 1\right) \frac{z}{H - h} \exp\left(1 - \frac{z}{H - h}\right)\right]. \quad (3)$$

Eq. (3) has three parameters: M, h and $u_{\max}$. The entropy parameter M is a function of the ratio between the mean, U_{m}, and maximum velocities, $u_{\max}$, and can be derived using the following relationship:

$$U_m = \Phi(M) u_{\max}, \quad (4)$$

in which

$$\Phi(M) = \frac{U_m}{u_{max}} = \frac{e^M}{e^M - 1} - \frac{1}{M}. \quad (5)$$

Eq. (4) shows that if a sample of (U_m, u_{max}) pair is given, then $\Phi(M)$ can be estimated from which the entropy parameter M can be calculated using Eq. (5).

Chiu's velocity distribution Eq. (3) is capable of describing the variation of velocity in both vertical and transverse directions, with the maximum velocity, u_{max}, occurring on or below the water surface. Araújo & Chaudhry (1998) confirmed that the entropy model performed better than the logarithmic model not only in general terms but also in all flow regions, especially in those near the channel bed. Moramarco *et al*. (2004) and Burnelli *et al* (2008) showed that the entropy-based velocity equation provides better consistency with measured data not only under normal flow conditions but also in the case of high flow. They also showed that using entropy concept method, personnel will be secure and the duration of the measurement is also significantly shorted.

Field measurements

Flow measurements were performed at four different cross-sections at four sites in central Turkey. Three of the sites are within the Kizilirmak basin. These stations are Bunyan, Sahsanem and Barsama on the Sarimsakli Stream, which is a tributary of the Kizilirmak River. Kizilirmak is the longest-flowing river within the boundaries of the Republic of Turkey and it drains into the Black Sea in northern Turkey (Fig. 1). The fourth station, named Sosun, is on the Sosun stream, which is a tributary of the Zamanti River in the Seyhan basin. Zamanti River flows southerly and drains to the Mediterranean Sea. Although the four stations are geographically close to each other, they all sit near the continental divide of the Black Sea and Mediterranean Sea Basins. Velocity measurements at the first three stations were carried out during six site visits to each site between 2005 and 2010. The Sosun station was visited four times for velocity measurements from May 2009 to April 2010. The water level was below the bankfull stage at each time point.

The velocity measurements were made using a Son Tek YSI FlowTracker Handheld (San Diego, CA, USA) ADV. The ADV measures the three-dimensional flow velocities (u, v, w) in a sampling volume using the Doppler shift principle and consists, basically, of a sound emitter, three sound receivers and a signal conditioning electronic module. The ADV sampling volume is located 10 cm in front of the probe head. Most of the practical and theoretical concepts related to the use of the acoustic Doppler principle by ADV and the acoustic Doppler current profiler in a small river are examined (Gunawan *et al*. 2010).

The flow characteristics at each site are summarized in Table 1. In the table, Q is the integrated discharge, U_m ($=Q/A$) is the mean velocity, with A being the area of the cross section, u_{max} is the measured maximum velocity at a given cross-section, Re ($=4U_mR/\upsilon$) is the Reynolds number, with R ($=A/P$) being the hydraulic radius, P being the wetted perimeter and υ being the kinematic viscosity, Fr ($=U_m/\sqrt{gH_{max}}$) is the Froude number, where g is the gravitational acceleration and H_{max} is the maximum flow depth at a given cross-section, and T/R is the aspect ratio, with T being the surface water width. As is clear from the Froude and Reynolds numbers given in the table, all the flow measurements were made under subcritical and turbulent flow conditions.

During flow measurements, cross-sections were divided into number of slices for each flow condition according to the water surface width. Point velocity measurements were made at different positions in the vertical direction starting 4 cm from the streambed for each vertical. It estimates the velocity of a free surface in

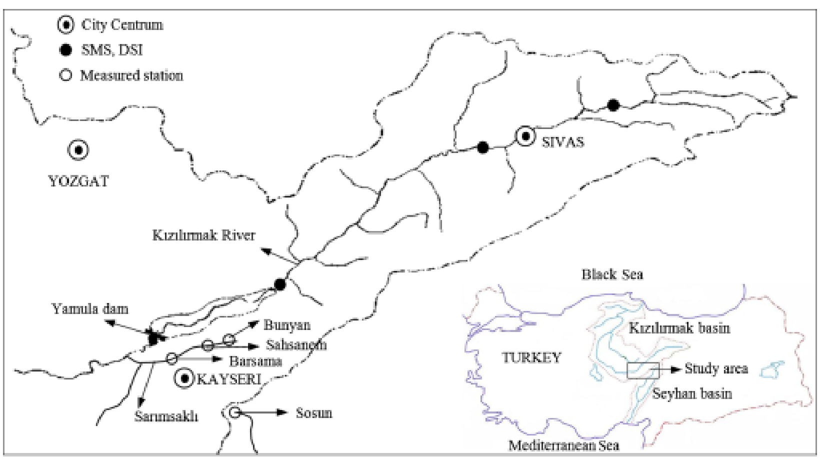

Fig. 1. Location of the study area and measurement stations, Bünyan, Sahsanem, Barsama and Sosun.

Table 1 Flow characteristics

	Dates (month/day/year)	Q (m^3/s)	U_{m} (m/s)	$u_{\max}$ (m/s)	Re ($\times 10^6$)	Fr	T/R
Bunyan_1	06/24/2009	0.788	0.354	0.595	7.1	0.133	7.0
Bunyan_2	08/02/2010	0.434	0.214	0.412	4.0	0.084	7.5
Bunyan_3	09/27/2009	0.636	0.301	0.593	5.0	0.113	8.2
Bunyan_4	04/04/2010	1.082	0.405	0.687	7.8	0.140	7.3
Bunyan_5	05/16/2010	1.188	0.426	0.671	8.5	0.147	7.0
Bunyan_6	06/20/2010	0.708	0.286	0.557	5.3	0.103	7.3
Sahsenem_1	03/29/2006	0.816	0.600	0.950	4.7	0.350	26.8
Sahsenem_2	10/20/2007	0.718	0.529	0.841	4.7	0.298	21.9
Sahsenem_3	02/22/2008	0.792	0.565	0.932	4.9	0.314	22.1
Sahsenem_4	05/03/2008	0.613	0.518	0.870	3.9	0.307	25.1
Sahsenem_5	10/11/2008	0.667	0.536	0.902	4.4	0.303	22.0
Sahsenem_6	11/08/2008	0.732	0.516	0.875	5.1	0.282	19.6
Barsama_1	05/28/2005	1.813	0.890	1.400	7.6	0.481	34.0
Barsama_2	05/19/2006	2.443	1.051	1.600	9.4	0.531	35.2
Barsama_3	05/19/2009	3.933	1.214	1.900	1.3	0.578	29.7
Barsama_4	05/31/2009	0.965	0.590	1.100	3.8	0.333	45.4
Barsama_5	03/24/2010	1.505	0.806	1.400	7.1	0.417	34.4
Barsama_6	04/18/2010	2.148	0.865	1.500	1.2	0.421	22.1
Sosun_1	05/19/2009	0.886	0.561	0.949	8.4	0.229	7.5
Sosun_2	05/31/2009	0.294	0.285	0.495	3.2	0.134	9.5
Sosun_3	03/24/2010	0.338	0.327	0.572	3.7	0.152	8.9
Sosun_4	04/18/2010	0.529	0.541	0.859	6.7	0.235	6.5

all verticals by extrapolating the last two measurements of verticals.

Data analysis and discussion

Discharge calculation

Discharge measurement is always an important task in river engineering. Flow data are needed for multiple purposes, such as flood forecasting, water resources management, hydrologic analysis and water quality monitoring. The most commonly method used in discharge measurement is the velocity-area method, but its utilization needs the average slice velocity and also the cross-sectional area for measured cross-sections. Further, this procedure requires considerable effort and time and it is very hazardous and almost impossible to measure flow during flood events. Thus, many empirical methods such as Chezy, Darcy–Weisbach and Manning's equations, which are called slope-area methods, have been developed. The Manning equation is probably the most commonly used empirical equation in discharge calculations. Although they are simple in nature, none of those empirical equations are very effective and they are all extremely sensitive to roughness parameters and are not easy to determine (Chow 1959).

Chiu & Said (1995) developed a technique for determining discharge from the entropy parameter M of an open channel section and the velocity profile on a single vertical, where the maximum velocity occurs in a channel cross-section. The M value of a channel section tends to remain constant as the velocity distribution fluctuates. The value of M being constant for a channel section can considerably simplify discharge determination.

Using Eq. (5), the entropy parameters, M_i (i=1,.., 4) were calculated for each measurement station. The entropy parameters, M_i, were determined to be 1.40, 1.30, 0.85 and 1.22 for Barsama, Sahsanem, Bunyan and Sosun stations, respectively. These values can be considered quite close to each other. When all the pairs of mean and maximum velocities from all four stations are plotted on the same graph, it is observed that there is a very strong linear relationship (R^2=0.98) between the mean and the maximum velocities (Fig. 2). The slope of this linear regression line is 0.61, which corresponds to $U_{\mathrm{m}}/u_{\max}$. When this value is used in Eq. (5), we obtain a global M value for all four stations of 1.31. Similar linear relations were observed in natural rivers for different stations located in same basins by Xia (1997) and Moramarco *et al*. (2004). Although not all of our stations are in the same basin, they have similar characteristics.

The similarity in the M values for each cross-section depends on the similarity of some channel characteristics such as bed form and material, geometrical shape and alignment, bed slope, etc. besides other physiographic features. Some flow characteristics such as Froude and Reynolds numbers can also affect the M value because the entropy parameter M is directly related to the mean

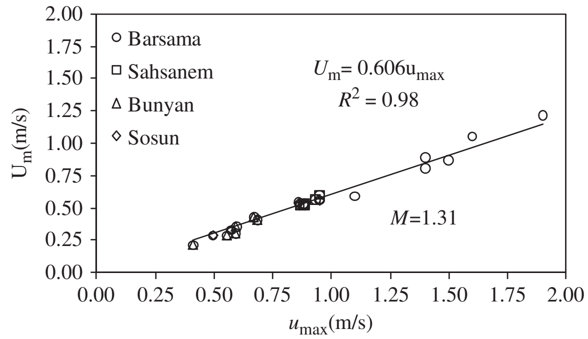

Fig. 2. Relation between U_m and u_{max} for four stations.

velocity. To clarify the effects of these parameters on the entropy parameter M, it is necessary to test this method on the same or other closed tributaries of rivers. Such an investigation is suggested for future study.

The accuracy of this linear relationship for the four gauged sections was investigated by evaluating the errors ε (%) defined as follows:

$$\varepsilon(\%) = \left|\frac{Q - Q_M}{Q}\right| \times 100, \qquad (6)$$

where Q and Q_M are the measured and the computed discharges, respectively. The error analysis was performed by considering four different discharge calculations. The first was constituted by the M_i of the each station. Cross-sectional mean velocities were calculated using the maximum velocities and the constant M_i value for all stations using Eq. (4). Discharges were also calculated as $Q_{M_i}$for all stations. The relative errors between measured (Q) and calculated (Q_{M_i}) discharges were determined using Eq. (6). Average errors vary from 1.7 to 8.4%. The average of mean errors for four stations was found to be 5.2%.The second method for discharge calculation is through the use of the concerted M value (=1.31) under all flow conditions and for all stations. As mentioned above, Eqs (4) and (6) were used for discharge and error calculations, respectively. The average of the mean errors for all stations was found to be 5.4%. This shows that if we know the M value for a river basin or as in our case for a geographic area, discharge can easily be determined using only the maximum velocity (u_{max}) information at a river cross-section.

Velocity distribution

Chiu's entropy-based velocity Eq. (3) is used for vertical velocity distributions along the cross-section at four stations. The number of vertical velocity measurements at each station was decided based on the cross-sectional flow area. The number of verticals we used for a given cross-section varied from four to nine. Using the global value of 1.31 for M that was obtained using measured data from all four stations, velocity distributions for each vertical were determined using Eq. (3). In this equation, u_{max} and z_{max} (=$H-h$) values were from measured data. A sample measurement and calculated velocity distribution is given in Fig. 3, for Barsama_2 measurements. In the figures, solid lines show the entropy-based velocity distributions (Ent_meas) obtained with M=1.31. As shown in the figures, the calculated velocities for some verticals exceed the measured values. However, the computed velocities mostly match very well with the measured velocities, especially near the bottom and free surface compared with the log law. In Fig. 4(a), vertical measurements and calculated velocities are given for six Barsama measurements only for the range $0.2 \leq y/T \leq 0.8$. Here, y denotes the horizontal distance from the side-wall. In other words, measurements from the verticals that are within 20% of the top width Talong each bank are not shown. As can be seen in Fig. 4(a), the velocities calculated using the entropy principle are generally higher than the measured values. The average error between the measured and the calculated velocities using the entropy Eq. (3) for all measurements is found to be 11.7% at the Barsama Station. Similar errors were observed for Sahsanem, Bunyan and Sosun stations and the relative errors were determined as 11.4, 13.2 and 12.0%, respectively.

This entropy calculation requires three parameters for vertical velocity distributions. These are entropy parameter M, maximum velocity u_{max} for each vertical and the depth z_{max} where u_{max} occurs. The challenge here is finding z_{max}. It is not easy to determine where the maximum velocity occurs and also what the magnitude of its value is. Finding z_{max} requires time and effort. Hence, a simple relation was sought for u_{max} and its depth (z_{max}=$H-h$) for each measured vertical. In Fig. 5(a–b), the u_{max}/H ratios along the cross-section for four measured stations are given. As shown in Fig. 5(a), the u_{max}/H ratios for $0.2 \leq y/T \leq 0.8$ are almost constant and with average u_{max}/H values of 0.041 and 0.029 for Barsama and Sahsanem stations given as a solid line, respectively. Standard deviations are also given and shown as a dashed line in the figure. The coefficient of variations (Cv) are very small for both stations, and are 0.13 and 0.11, respectively. Similar relationships were observed for Sosun and Bunyan stations, again Fig. 5(b) for $0.2 \leq y/T \leq 0.8$. The average of the u_{max}/H ratios for Sosun and Bunyan stations were found to be 0.013 and 0.006, respectively, with coefficients of variations 0.18 and 0.23, respectively. These values are slightly higher than the ones obtained for Barsama and Sahsanem stations, which had large aspect ratios ($T/R > 20$). As shown in Table 1, the aspect ratios T/R for Sosun and Bunyan stations are smaller than 10. We speculate that the u_{max}/H ratios could be constant in wide channels ($T/R > 20$).Near the side walls ($0<y/T<0.2$ and $0.8<y/T<1.0$), the $u_{\max}/H$ ratios become more erratic with no clear trend. In the proximity of side-walls, many factors affect the flow properties, such as the size and shape of the bed materials and plant tissue, which could quickly change in time. In natural open channel flows, these regions usually convey less than 20% of the flow discharge. Further, it is also easier to measure flow in areas where $y/T<0.20$ and $y/T > 0.80$, because of easier accessibility and navigability. In our study sites, the fraction of flow passing through these near side-wall areas varied between 12.8 and 22.7%. Therefore, the determination of flow properties for the $0.2 \leq y/T \leq 0.8$ portion of cross-section is more important. If the constant average value of the $u_{\max}/H$ ratios is known for a given cross-section, we can easily obtain the maximum velocity from the flow depth at any vertical of the cross-section.

To calculate the vertical velocity distribution in natural streams using the entropy equation given in Eq. (3), one needs to know the maximum velocity depth [shown as h in Eq. (3)]. Maximum velocity usually occurs below the water surface and its exact location is defined by the free surface and side-wall effects. This phenomenon is known as the dip effect. In Fig. 6(a–b), the $z_{\max}/H$ ratios along the cross-section for the four measurement stations are given.

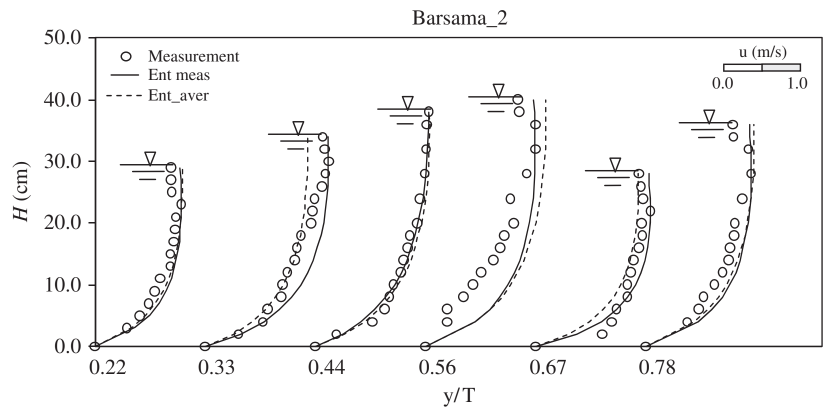

Fig. 3. Measured and calculated velocity distributions for Barsama_2 measurements.

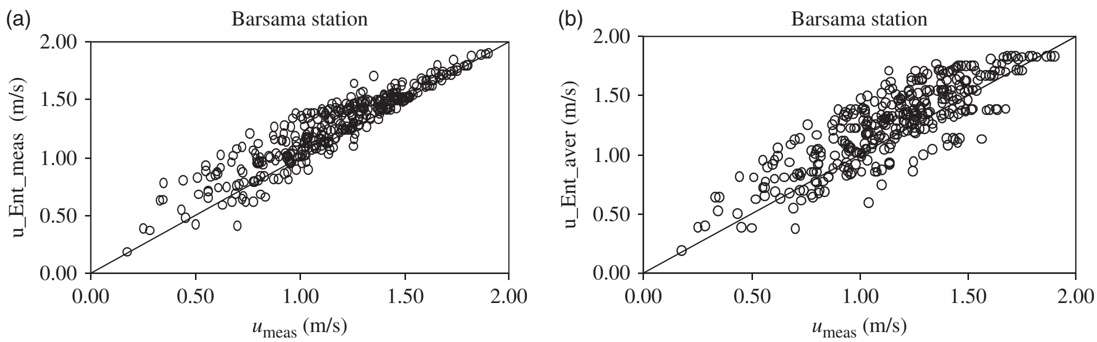

Fig. 4. Measured and calculated velocity distributions for Barsama station. (a) Classical entropy calculations, (b) Average entropy calculations.

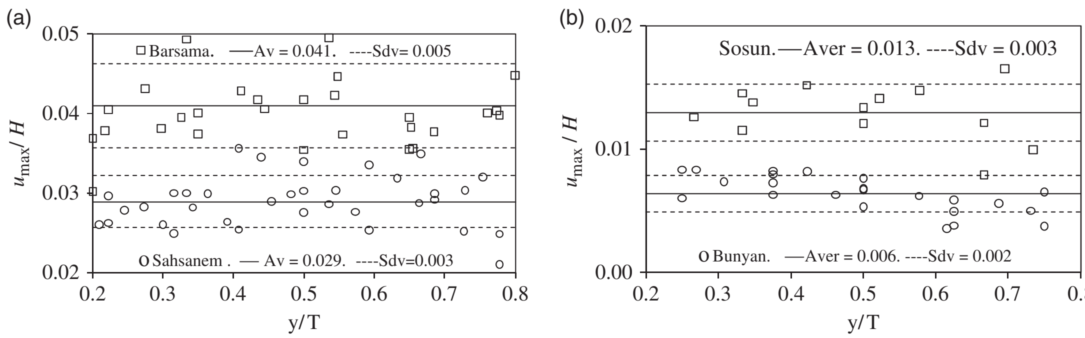

Fig. 5. $u_{\max}/H$ ratio along the cross-section for measured stations. (a) Barsama & Sahsanem, (b) Sosun & Bunyan.

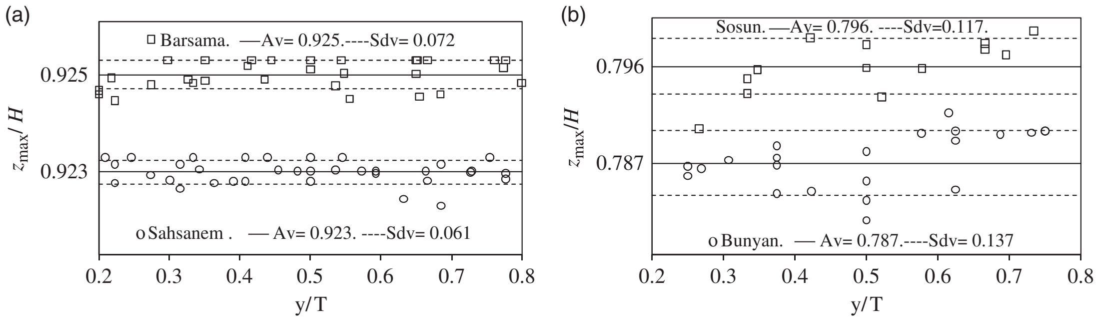

Fig. 6. z_{max}/H ratios along the cross-section for measured stations. (a) Barsama & Sahsanem, (b) Sosun & Bunyan.

As shown in these figures, the $z_{\max}/H$ ratios are also almost invariant in the $0.2 \leq y/T \leq 0.8$ range of the cross-sections.

As shown in Table 1, the aspect ratios (T/R) vary between 6.5 and 45.4 for the studies sites under different flow conditions. At Sosun and Bunyan stations, the aspect ratios are <10 and the average $z_{\max}/H$ ratios are 0.796 and 0.787, respectively. The Cv of these values for Sosun and Bunyan station are found to be 0.15 and 0.17, respectively, Fig. 6 (b). These Cv values are slightly higher than the Cv values of the $u_{\max}/H$ ratios but still within an acceptable range. Therefore, for our study region in channels with $T/R<10$, the depth where maximum velocity occurs is almost constant and is given by $z_{\max}/H \cong 0.79$–0.80. Using this ratio, we can obtain the maximum velocity position and measure the maximum velocity in the vicinity of this depth.

As shown in Fig. 6(a) for Barsama and Sahsanem stations, the $z_{\max}/H$ ratios become 0.925 and 0.923, respectively. In these cross-sections, $T/R > 19.6 \cong 20.0$ under all measured flow conditions. In these stations, the Cv were determined to be 0.08 and 0.07, respectively. It is clear that in wide channels ($T/R \geq 20$), the maximum velocity depth is almost constant with $z_{\max}/H \cong 0.92$–0.93. Note that the $z_{\max}/H$ values in wider channels are higher than the ones in narrow channels ($T/R<10$).

If the constant average value of $z_{\max}/H$ ratio is known at a cross-section, we can obtain the depth at which the maximum velocity occurs at any vertical of the cross-section. Using the constant ratios of both $u_{\max}/H$ and $z_{\max}/H$, we can find $u_{\max}$ and $z_{\max}$ values at any vertical of the cross-section. Using the constant entropy parameter M ($=1.31$ for our study sites) and these known $u_{\max}$ and $z_{\max}$ values, the velocity profile can be obtained by Eq. (3) for any vertical.

Entropy-based Chiu's velocity equation is used for four different cross-sections mentioned above. In Fig. 4, the velocity profiles calculated with the entropy equation using the average values of $u_{\max}$ and $z_{\max}$ are given for Barsama_2 measurements. In each profile, the calculated velocities are shown with dashed lines and are denoted as Ent_aver in the figure legend. It can be seen that the calculated velocities for some of the verticals are again larger than the measured velocities. In Fig. 4(b), for verticals in the range $0.2 \leq y/T \leq 0.8$, measurements and calculated velocities are given for the six Barsama station measurements. As can be seen from the figure, velocities calculated by the average entropy principle are generally larger than the experimental values. The average error between the measured and the calculated velocities using entropy Eq. (3) for all measurements is found to be 14.7% at the Barsama station. Similar results were observed for Sahsanem, Bunyan and Sosun stations, where relative errors were determined to be 13.4, 23.1 and 19.6%, respectively. Note that the relative errors for narrow channels ($T/R<10$) are higher than the errors in wide channels ($T/R > 20$).

Summary and conclusions

The entropy-based discharge and velocity distribution equation is used for the determination of flow properties in natural streams. The linear relationship between the mean and the maximum flow velocities is found to be accurate at four different cross-sections, with an entropy parameter of $M=1.31$ representative of all sites. This means that for cross-sections that have the same characteristics, a global entropy parameter M can be defined. Using this global M value, discharges for all flow conditions were calculated using the measured maximum velocity ($u_{\max}$). The average relative error was found to be 5.4%. The $u_{\max}/H$ and $z_{\max}/H$ ratios were investigated at the four sites. We found that those ratios varied very little when y/T was between 0.2 and 0.8. Using these constant ratios, at each station, $u_{\max}$ and $z_{\max}$ could be determined using water depth. The entropy velocity equation was applied for each vertical and flow condition. Calculated velocities were higher than those measured for some verticals; however, considering the simplicity of its application, this method could serve as a cheap and practical alternative for the estimation of flow discharge and velocity distributions. The average errors between the measured and the calculated velocities using entropy Eq. (3) for all flow conditions were found to be 14.7 and 13.4% for Barsama and Sahsanem stations, respectively. Water depth H is an easily obtainable measurement along the cross-section of a stream. Especially in wide streams, ($T/R \geq 20$), using known u_{max}/H and z_{max}/H ratios, u_{max} and its position z_{max}, which are the basic parameters for entropy methods, the flow discharge can be calculated easily.

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