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Randomness representation of Turbulence in an alluvial channel affected by downward seepage

Anurag Sharma [a], Dragutin T. Mihailović [b], Bimlesh Kumar [c,*]

[a] Department of Civil Engineering, Parala Maharaja Engineering College, 761003, India
[b] Faculty of Agriculture, University of Novi Sad[1], Serbia
[c] Department of Civil Engineering, Indian Institute of Technology Guwahati, 781039, India

HIGHLIGHTS

- The randomness of turbulence is quantified through Kolmogorov complexity (KC).
- Higher value of KC indicates that higher level of randomness with seepage.
- Hilbert–Huang transform is used to measure the time scales in velocity time series.
- Spectral analysis suggests more randomness in channel with seepage.
- Higher randomness can be linked to the size of turbulent eddies.

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ABSTRACT

In the present work, experimental investigations have been done to study the flow turbulence in an alluvial channel with and without seepage. Turbulence is generally depicted as flow randomness or irregularity. The inherent randomness of turbulence in seepage affected channel has been quantified through Kolmogorov complexity (KC) and the Kolmogorov complexity spectrum. The measures have been used in analysis of the velocity time series data of alluvial channel to compare the degree of turbulence with and without seepage. The result concludes that the value of the KC is higher with seepage flow which indicates that higher level of randomness has been observed in seepage flow. Also, the frequency analysis of velocity time series was carried out with the help of Hilbert–Huang transform, which shows that dominant time scale for seepage flow is lower, indicates increased rate of sediment transport. Spectral analysis of velocity time series also suggests more randomness in channel with seepage.

1. Introduction

The occurrence of seepage flow out from the channel or into the channel causes morphological changes [1–3] owing to variation in bed shear stress and velocity. Also, the interface of the channel and seepage flow in an alluvial channel forms a current which disturbs the channel flow turbulence [4]. Alluvial channels can have a wide range of seepage discharge (approximately 10–50% of main channel discharge) depending upon the field specific conditions [5,6]. These studies are performed on a field i.e. on a large scale, thereby; exact scaled model cannot be used in the experimental study. Therefore,

* Corresponding author.
E-mail addresses: gokarna29@gmail.com (A. Sharma), guto@polj.uns.ac.rs (D.T. Mihailović), bimk@iitg.ac.in (B. Kumar).
1 https://www.researchgate.net/institution/University_of_Novi_Sad.

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Table 1
Effect of seepage on channel hydrodynamics.

Authors	Flume dimensions			Type of sand	Seepage effects			
	Length (m)	Width (m)	Seepage zone (m)		Bed shear stress		Sediment transport rate	
					US	DS	US	DS
Watters and Rao [23]	4.6	0.7	1.5	Uniform	NA	NA	–	+
Oldenziel and Brink [27]	15	0.5	4	Uniform	NA	NA	+	–
Willetts and Drossos [28]	3.6	0.076	0.125	Uniform	NA	NA	NA	+
Richardson et al. [9]	9.45	0.6	3	Uniform	NA	NA	+	–
Maclean and Willetts [29]	5	0.076	5	Uniform	NA	+	NA	NA
Maclean [19]	12	0.3	0.28	Uniform	NA	+	NA	NA
Maclean [30]	5	0.075	0.13	Uniform	No	+	No	+
Cheng [31]	7.6/30	0.21/0.7	0.5/2	Uniform	–	NA	+	NA
Cheng and Chiew [25]	30	0.7	2	Uniform	–	NA	NA	NA
Cheng and Chiew [32]	7.6	0.21	0.5	Uniform	–	NA	+	NA
Rao and Sitaram [33]	3.6	0.158	2.4	Uniform	+/–	+/–	–	+
Krogstad and Kourakine [21]	3.5	0.46	0.12	Uniform	–	NA	NA	NA
Chen and Chiew [20]	30	0.7	2	Uniform	NA	+	NA	NA
Lu and Chiew [24]	30	0.7	2	Uniform	NA	NA	–	+
Sreenivasulu et al. [4]	25	1.8	20	Uniform	NA	+	NA	NA
Rao et al. [34]	25	1.8	16	Uniform	NA	NA	NA	+
Cao and Chiew [7]	9	0.3	0.5	Uniform	NA	NA	NA	+
Patel et al. [12]	17.2	1	15	Uniform	NA	+	NA	+
Deshpande and Kumar [13]	17.2	1	15	Uniform	NA	+	NA	+
Devi et al. [26]	17.2	1	15	Uniform	NA	+	NA	+
Sharma and Kumar [15]	17.2	1	15	Non-uniform	NA	+	NA	+

(US) upward seepage, (DS) downward seepage, (+) Increasing, (–) Decreasing, (NA) Not applicable.

the aim is to find out the appropriate amount of the seepage losses in an alluvial channel used in the experimental study. In experimental studies, many literatures [7–9] measured seepage velocities in an alluvial channel and observed value of seepage velocity in the range of 0.0 to 7.3 mm/s. Moreover, many experiments were carried out by considering different seepage discharge in the form of seepage velocities to study the seepage effect on the channel hydraulics. Based on the percentage ratio of seepage to surface flow velocity as (0.33–1.11), Liu and Chiew [10] experimentally analyzing the forces acting on a single bed particle with downward seepage. Cao et al. [11] took the downward seepage velocity rate (in percent) as (0.14–12.30) in order to experimentally measure horizontal and vertical velocities near a bed of closed-conduit flows in the presence of downward seepage. In experimental investigation of turbulent structure with seepage, previous studies [12,13] considered the percentage of seepage velocity as (0.097–0.15)% of the surface flow velocity. Herrera-Granados and Kostecki [14] proposed the criteria to consider the seepage velocity based on laboratory in the natural system. Their experimental observation shows that the ratio of upward seepage to surface flow velocity (in percent) during the experiments was in between (0.0054–0.0133). In the recent studies [15–17], downward seepage velocity is considered as (0.08–0.12)% of the surface flow velocity in a non-uniform sand bed channel.

Various researchers [13,15,17] were carried out the experiment to observe the changes in flow turbulence owing to seepage. Their findings about the effects of downward seepage and upward seepage on turbulent parameters are summarized in Table 1. However, bed material movement in alluvial channel is extremely affected by the occurrence of seepage. In previous studies, whose authors are summarized in Table 1, the influence of seepage is obviously noticeable on the turbulent flow structures. Nezu [18] found that the higher velocity zone is achieved towards the boundary due to downward seepage and it is moved away from the boundary in the presence of upward seepage. Maclean [19] and Chen and Chiew [20] found increased near bed flow velocity in the occurrence of downward seepage. Krogstad and Kourakine [21] and Oyewola et al. [22] found increased anisotropy in the near-bed zone of flows influenced by downward seepage. With the application of downward seepage, Watters and Rao [23] found increased hydrodynamic roughness and reduced intensities of turbulence with reduced momentum interchange between fluid particles. Lu and Chiew [24] and Deshpande and Kumar [13] have found that turbulent intensity reduces with downward seepage and increases in the presence of upward seepage [25]. Liu and Chiew [10] detected increased velocity towards the boundary in the case of downward seepage and decreased velocity in the case of upward seepage. Patel et al. [12] found that integral length scale increase with seepage flow which caused increased bed material transport in the presence of downward seepage. Devi et al. [26] found that dimensionless turbulent intensity increases in the presence of downward seepage flow. Herrera-Granados and Kostecki [14] observed that upward seepage affects the instantaneous water flow velocity of the open channel and its turbulence characteristics. In the recent study over non-uniform sand bed channel [15,17], the stream wise velocity, Reynolds shear stress and turbulent intensity increases with downward seepage while the turbulent diffusivity and the Prandtl mixing length decreases with downward seepage.

The literature as discussed above suggests in tandem that there is increased level of turbulence with downward seepage, which initiates the bed material movement. The reference of increased level of turbulence has been quantified with measures of statistical properties of velocity time series. Traditional statistical methods are typically depending on norms which are