Overwash hazards assessment using a simplified process based approach.

Evaluación de riesgos de desbordamiento utilizando aproximación simplificada de los procesos básicos.

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Abstract: Coastal communities are threatened by the impact of severe storms that may cause significant loss or damage of property and life. One of the main processes behind such impacts is the overwash of coastal barriers. In order to estimate the losses associated with a particular event, overwash must be properly parameterized. Here, we propose a novel approach to estimate potential overwash hazards, which includes the associated major processes and crucial parameters. For that purpose it was used the parametrisation of the physical processes developed by Donnelly (2008), and the overwash hazard was related to both flow velocity and flow depth, which are in turn a function of lateral spreading of the flow and percolation.

The proposed method requires the selection of a validated run-up formula for the study area; a percolation constant for infiltration; a typical value for the run-up lens; and a storm beach profile. Combining these parameters, the overwash depth and velocity for different return periods can be estimated together with the associated hazards. The advantages of the present approach are: adaptability to any environment where overwash processes are important, time efficiency on evaluating overwash hazards, and the assessment of hotspot areas at a regional scale (tens to hundred kilometres).

Key words: *hazard assessment, storms, coastal barriers, overwash.*

Resumen: Las comunidades costeras están amenazadas por el impacto de tormentas severas que pueden causar pérdidas significativas sobre infraestructuras y vida. Uno de los principales procesos detrás de este tipo de impactos es el desbordamiento de barreras costeras. Para estimar las pérdidas asociadas a un evento en particular, el desbordamiento debe ser correctamente parametrizado. Este trabajo propone un nuevo enfoque para estimar el potencial de peligrosidad asociado al desbordamiento incluyendo sus procesos principales y parámetros decisivos. Para ello se consideró la parametrización de los procesos físicos desarrollada por Donnelly (2008), y se relacionó el peligro de desbordamiento con la velocidad y la profundidad del flujo, los cuales son a su vez función de la propagación lateral del flujo y la percolación.

El método propuesto requiere la selección de una fórmula de run-up validada en el área de estudio; una constante de percolación para la infiltración; un valor típico para la lente de run-up; y un perfil de playa de tormenta. Combinando estos parámetros es posible estimar la profundidad y la velocidad de desbordamiento para diferentes períodos de retorno junto con los peligros asociados. Las ventajas del presente enfoque son: capacidad de adaptación a cualquier ambiente donde los procesos de desbordamiento son importantes, la eficiencia en el tiempo en la evaluación de riesgos, y la evaluación de las zonas sensibles a escala regional (de decenas a cientos de kilómetros).

Palabras clave: *evaluación de peligrosidad, tormentas, islas barreras, desbordamiento.*

INTRODUCTION

Densely populated coastal areas are very likely to face risks derived from intense extreme events capable of provoking the inundation or overwash with severe consequences over human goods or life. In an attempt to reduce the latter, an effort must be taken on coastal areas to identify more vulnerable areas and threats.

Overwash related to extreme events is among the major hazards in low-lying areas. Yet, the elevated complexity of the process has traditionally inhibited its consideration when assessing coastal risk.

Nowadays, extended numerical morphodynamic models have been developed for calculating overwash and coastal erosion (Roelvink et al., 2009; McCall et al., 2013) and they are widely used. However, their application demands high computational capacities and input data making them in general restricted to local scale.

Here, we develop an approach to assess coastal risk induced by overwash through the simplification of the overwash process to allow its fast application at large spatial scale on the identification of hot spot areas where overwash may turn to be a major hazard. The present approach provides an estimation of flow velocity and water depth of the overwash events that can be used to estimate the exposure of infrastructure and/or other assets in the coastal environment. Finally, once the hotspot areas have been identified a more detailed evaluation can be undertaken by employing a high resolution two dimensional numerical model such as XBEACH.

PROPOSED APPROACH

The proposed approach is based to the similarity relationship developed by Donnelly (2008) for runup estimation under overwash flow regime (Sallenger, 2000). The latter implies that inundation regimes cannot be estimated following this approach.

The applied relationship estimates the water depth at the crest of the profile (h_c) based on the assumption that the water profile is linear during the runup (Figure 1),

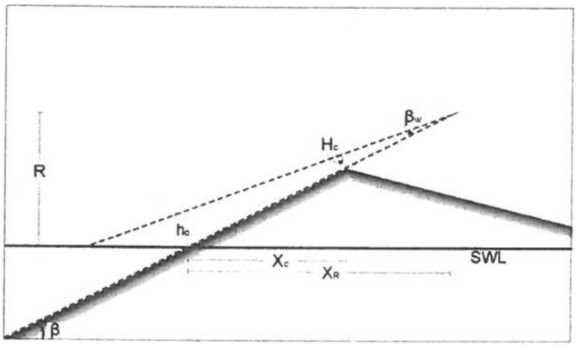

FIGURE 1. *Sketch showing the assumed water level at maximum run-up, and the linear relationship used to estimate water depths (adapted from Schuettrumpf and Oumeraci, 2005).Definition of variables is given along the text.*

$$h_c = \frac{h_o}{x_R}(x_R - x_c) \qquad (1)$$

where X_C is the horizontal distance from the shoreline position at sea water level (SWL, i.e.Sea Level plus surge) to the beach crest, and X_R is the horizontal projection of the maximum potential runup from the shoreline (Figure 1). The value of X_R can be estimated as the product of R, which is the maximum runup vertical extension obtained applying an overwash equation suitable for the study area (e.g. Holman, Stockdon etc.), and the beachface slope. The value of X_C can be directly estimated from the beach profile or any other topographic information. Finally, h_o refers to the wave height of the overwash bore at the start of the uprush and cannot be easily estimated. Donnelly (2008) substitutes the h_o/X_R term by a constant value based on laboratory measurements and on the work carried out by Schuettrumpf and Oumeraci (2005) where the tangent of the run-up lens ($\tan\beta_w$) was measured. Typical values of $\tan\beta_w$ are presented in Table I for different slopes. The h_o/X_R and the tangent of the run-up lens are not exactly identical, assuming a linear water surface. Hence, the equation can be rearranged to be trigonometrically more accurate using the same similarity relation to:

$$h_c = \frac{\tan\beta_w x_c}{x_R \cos\beta}(x_R - x_c) \qquad (2)$$

where β is the beach slope. The values of $\tan\beta_w$ can be again obtained from Table I. The experiments were undertaken for dike overtopping; hence, the slopes are in general reflected.

Once the overwash depth at the barrier crest is obtained, the flow velocity at the crest (u_c) can be calculated as :

	tanβw	tanβ	r
hc2%	0.035	0.17	0.60
hc2%	0.028	0.25	0.42

TABLE I. *Run-up lens slope measured for dikes (laboratory measurements in slopes 1:6) after Schuettrumpf and Oumeraci (2005).*

$$u_c = C_u\sqrt{g h_c} \qquad (3)$$

where C_u is the bore front coefficient that can take the following values: 1.53 in sandy beaches (Donnelly 2008), 2 (analytical dam break solution) or 2.6 in gravel barriers (Matias et al., 2014).

The variation of h_c and u_c can be estimated analytically for the backbarrier zone (Donnelly, 2008). However, to simplify the present approach we will associate the evolution of h_c in the backbarrier zone with the loss of volume due to infiltration, assuming that there is no lateral widening of the flow. This profile approach assumes that overwash is longitudinally homogeneous, i.e. it is produced by a long-crested wave using the following equation:

$$h(x) = h_c \exp(-a\frac{x}{u_c}) \qquad (4)$$

where α is the proportionality constant for infiltration.

Based on this equation, we can parameterise the exposure of backbarrier infrastructures assuming an infiltration constant while the rest of the values will depend on the wave conditions and the barrier geometry. In our case, a constant value is assumed for infiltration for the entire cross-shore profile. However, the value of infiltration can change per area or even along the profile, for example, one value for dunes and a different value for constructed surfaces (impermeable).

The evolution of the overwash velocity u_c across the backbarrier is also variable but has a more complicated analytical solution since it depends on the slope and on the bottom friction. Hence, in order to calculate it, one more parameter (friction coefficient) is required. The latter is difficult to estimate and could vary substantially along the profile. Thus, due to this complexity and the fact that the objective of the proposed methodology is a quick evaluation of potential overwash hazards, the crest velocity can be assumed constant as a worst case scenario. Finally, total overwash volumes can also be calculated by multiplying the u_c and h(x) and assuming a time frame

APPLICATION

The proposed methodology can be easily applied to numerous profiles along a stretch of coast. Here, we will show its application on a profile extracted from a sandy peninsula (Ancao Peninsula) located at the western flank of Ria Formosa, southern Portugal (Figure 2), where a small but densely populated coastal community (Praia de Faro) has settled in recent decades.

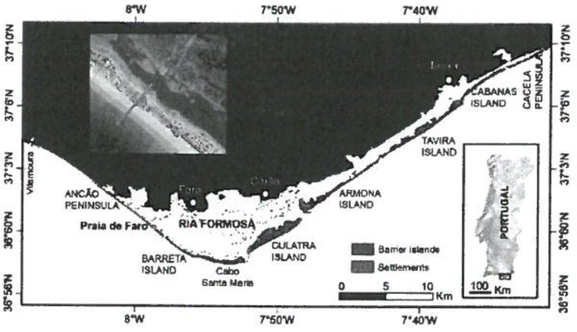

FIGURE 2. *Regional map of the study area including the position of the profile where the method was applied.*

The used barrier profile (Figure 3) runs across the most vulnerable area of the Praia de Faro settlement. Furthermore, the selected profile represents the most monitored section of the Ria Formosa coastline in terms of overwash. The profile was extracted from the most recent DTM (May 2011) available for the study area.

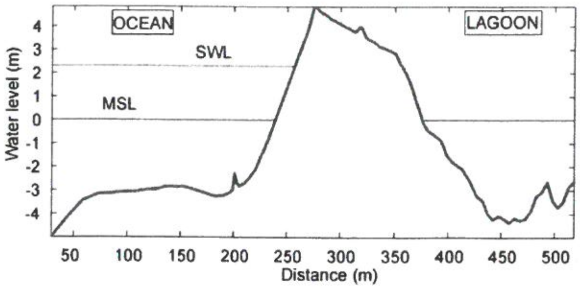

FIGURE 3. *Profile and key water levels for the 50 years return period event.*

The event selected has a 50 years return period with Hs=8.5 m and wave period Tp=14 sec. The associated tide and storm surge for this event resulted in a water level 2.33 m above MSL (Vousdoukas et al., 2012).

The theoretical runup was calculated using the Holman (Holman, 1986) formula, which is considered the best formula for the study area according to Vousdoukas et al. (2012) and Almeida et al (2012). Dune crest elevation, and beach and backbarrier slopes were calculated from the DTM. The results indicate a value of 0.12 for the beach face slope, and a dune crest 4.8 m above MSL. For the given event, the horizontal distance from the shoreline position at SWL (X_C) was 32 m long.

Using the obtained parameters from the beach profile and the wave conditions, the runup elevation was estimated at 5.7 m on top of the maximum SWL. This translates onto a vertical runup reaching 8.04 m above MSL and 48 m of potential horizontal run up excursion (X_R).

Substituting the values on equations (1) and (2) using the value of 0.035 from Table I, as the more appropriate for h_o/X_R **and** $\tan\beta_w$ coefficients, the obtained overwash flow depth at the crest (H_C) was estimated to be 0.49 m and 0.34 m respectively. Equation (1) produced a higher value of H_C than equation (2).

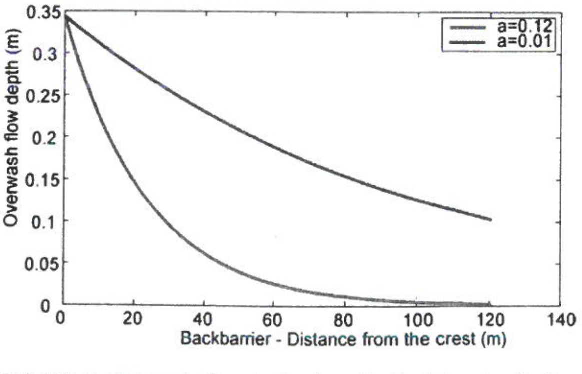

FIGURE 4. *Overwash flow depth along the back barrier for two different proportionality constants for infiltration (a). A high infiltration coefficient suitable for sandy barrier islands and a lower one more suitable to compact or almost impermeable surfaces.*

Runup is a high turbulent flow, which results in a mixture of water and air that is very difficult to measure accurately with pressure sensors. As a result, field measurements are sparse and with large scatter. Despite these limitations, in situ observations during an event of similar magnitude suggested overwash depths at the crest between 30 and 40 cm. This implies that equation (2) provides estimations that are closer to reality. This is probably because it also takes into account the slope of the beach face and this trigonometric adjustment is probably acting as a correction term. The associated runup velocity at the crest was obtained using equation (3) and was found to be 2.9 m/s using a C_u value of 1.53. If the same coefficient is applied using the flow depth from equation (1), the runup velocity will raise about 15 % up to 3.36 m/s.

Finally, the application of equation (4) allowed us to calculate the overwash depth assuming a coefficient for the loss of water due to infiltration α. Figure 4 shows the results for the calculation of the flow depth along the backbarrier using two values for the infiltration constant α=0.01 (almost impermeable bed) and α=0.12 (typical values for barrier islands with similar sedimentary and morphological conditions as Ria Formosa; Donnelly et al., 2006).

CONCLUSIONS/IMPLICATIONS

The present work provides a reliable, and time and spatial efficient methodology for parameterizing overwash hazards based on datasets of easy access. A rearrangement of the original equation from Donnelly, (2008) was attempt in order to introduce the tangent of the run-up lens. Despite the small angles observed the new equation seems to provide more accurate results for the study area.

This approach is particularly useful for assessing overwash impacts derived from an event as it provides reliable estimates of overwash water depths, length of overwash intrusion, and maximum flow velocities during the overwash. These parameters will ultimately determine to which extent coastal assets can or cannot be damaged and thus which areas are facing greater risks or define hot spot areas. For that, the obtained parameters must be integrated with available socio-economic information of the occupied coastal areas, including a description of the different types of land uses, population densities, building characteristics (e.g. building materials, storey number, etc.) and other assets (electricity, water,...) in order to assign different levels of risk and support decision making strategies of management and disaster risk reduction.

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REFERENCES

Almeida, L.P., Vousdoukas, M.V., Ferreira, O., Rodrigues, B.A. and Matias, A., 2012. Thresholds for storm impacts on an exposed sandy coastal area in southern Portugal. *Geomorphology*, 143-144(0): 3-12.

Donnelly, C., 2008. *Coastal Overwash: Processes and Modelling.* Phd Thesis Thesis, Univeristy of Lund, 53 pp.

Donnelly, C., Ranasinghe, R. and Larson M. 2006. Numerical Modeling of Beach Profile Change Caused by Overwash. *Coastal Dynamics* 2005: pp. 1-14.

Holman, R.A., 1986. Extreme value statistics for wave run-up on a natural beach. *Coastal Engineering*, 9(6): 527-544.

Matias, A., Blenkinsopp, C.E. and Masselink, G., 2014. Detailed investigation of overwash on a gravel barrier. *Marine Geology*, 350: 27-38.

McCall, R. et al., 2013. Predicting overwash on gravel barriers. *Journal of Coastal Research*: 1473-1478.

Roelvink, D. et al., 2009. Modelling storm impacts on beaches, dunes and barrier islands. *Coastal Engineering,* 56(11-12): 1133-1152.

Sallenger, A.H., 2000. Storm impact scale for barrier islands. Journal of Coastal Research, 16(3): 890-895.Schuttrumpf, H. and Oumeraci, H., 2005. Layer thicknesses and velocities of wave overtopping flow at seadikes. *Coastal Engineering*, 52(6): 473-495.

Vousdoukas, M., Wziatek, D. and Almeida, L., 2012. Coastal vulnerability assessment based on video wave run-up observations at a mesotidal, steep-sloped beach. *Ocean Dynamics*, 62(1): 123-137.