Is salt-water intrusion length reliable indicator for sea-level rise impacts in highly stratified estuaries?

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ABSTRACT

This study examines indicators for sea-level rise (SLR) impact assessment in highly stratified estuaries. One of the most common SLR indicators in highly stratified estuaries is the salt-water intrusion length, which is expected to increase with rising sea levels. However, we show that intrusion length can produce misleading results under the influence of the channel geometry. Namely, the intrusion length may appear to be unaffected by SLR if the channel slope prevents a potential salt-water intrusion further upstream. Although salt-water volume can be a more reliable indicator in those cases, we show that the corrective freshwater flow rate is a much better choice for assessing the practical implications of SLR from the viewpoint of adaptation to climate change and implementation of suitable mitigation measures. For this purpose, we present some findings from the theoretical analysis of two-layer shallow water equations and numerical simulations in the Neretva River Estuary in Croatia.

1. Introduction

One of the most serious consequences of ongoing climate change is the sea-level rise (SLR), which has been recognized as a major threat to low-lying coastal environments (IPCC, 2013). Estuaries are particularly vulnerable to SLR, especially in the context of freshwater usage for water supply or agriculture. Therefore, understanding the response of estuaries to SLR is crucial in developing suitable mitigation strategies.

In the past decade, numerous studies have investigated the impacts of SLR on estuarine dynamics. Many of these studies have found that SLR may increase the average salinity and force the salt-water intrusion further upstream (e.g. Krvavica et al., 2017b). Increased salt-water intrusion length L is usually highlighted as the main indicator for quantifying the SLR impacts. However, we found that the dynamics of highly stratified estuaries are sensitive to channel geometry. In other words, a potential salt-water intrusion may be prevented by the channel bed slope. Therefore, we recently examined how may this process affect the assessment of SLR and evaluated the suitability of two alternative indicators – salt-water intrusion volume V and the corrective freshwater flow rate q_{corr} (Krvavica and Ružić, 2020).

2. Methodology

In highly stratified estuaries, the upper layer of freshwater flows towards the mouth over a lower salt-water layer, sometimes called salt-wedge, which intrudes upstream. These two layers are separated by a thin pycnocline. In ideal (microtidal or tideless) conditions, the dynamics of highly stratified estuaries can be accurately represented by a two-layer hydraulic theory.

In a recent paper (Krvavica and Ružić, 2020), we first evaluated the potential SLR impacts in ideal highly-stratified estuaries – defined by prismatic channels and a horizontal bed - to remove the influence of the channel geometry, which is specific for a given location. Next, we performed a series of numerical simulations in the Neretva River Estuary in Croatia using a one-dimensional (1D) two-layer model STREAM 1D (Krvavica et al., 2017a). In both cases, we considered SLR up to 100 cm and quantified three indicators L, V, and q_{corr}. Some of these results are presented here to illustrate the impacts of channel geometry in the Neretva River Estuary and to highlight the need to use several different indicators when quantifying SLR impacts.

3. Results

Figure 1 shows two numerical results from the 1D numerical model; the longitudinal profile of the Neretva River Estuary for a small river flow rate Q=50 m^3s^{-1} and two sea levels – baseline level 0.0 m a.s.l, and potential SLR of +1.0 m a.s.l. It seems as the salt-water intrusion length is nearly unaffected by SLR. However, as a result of SLR, we can expect about 1.0 m increase in the salt-water layer thickness, as well as the salt-water volume by 20%, which may pose significant pressure on the groundwater and soil salinization. Furthermore, the freshwater flow rate needs to increase by 70% (from 50 to 85 m^3s^{-1}) to restore the baseline conditions.

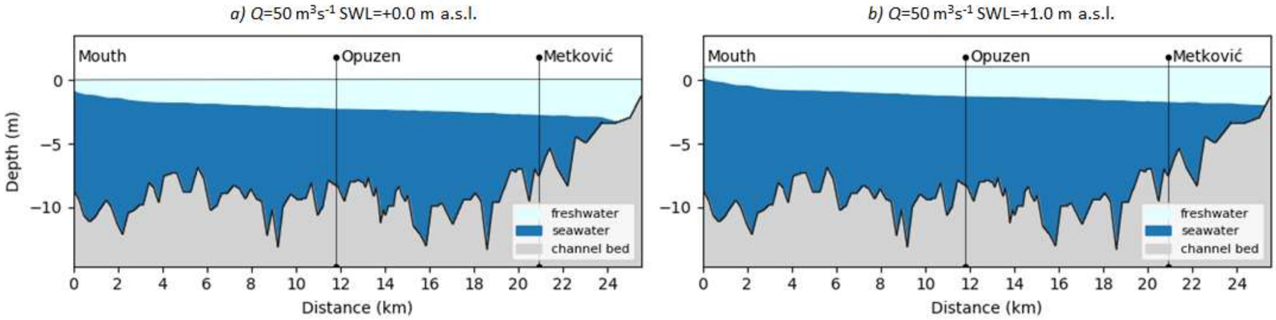

Fig. 1. Longitudinal profiles in the Neretva River Estuary obtained by a 1D two-layer numerical model for river flow rate Q=50 m^3s^{-1} and two SLR: a) baseline condition 0.0 m a.s.l., b) potential future SLR +1.0 m a.s.l. (Krvavica and Ružić, 2020)

Figure 2 presents the comparison of theoretical increases of the salt-water length, volume and corrective river flow rates in an idealized (horizontal) channel and the Neretva River Estuary. It is noticeable that theoretical analysis predicts much larger salt-water intrusions and volumes. On the other hand, the corrective river flow rates are lower in the idealized channel than in the Neretva River Estuary.

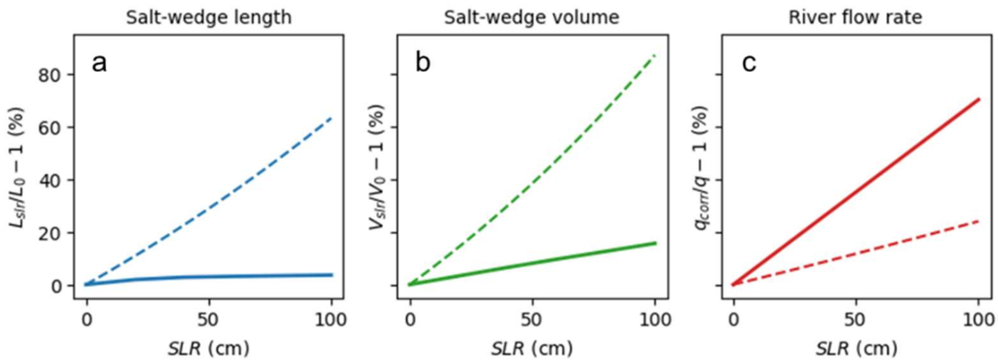

Fig. 2. Relative increases of the SLR indicators, full line (-) denotes the numerical results for the Neretva River Estuary, and dashed line (--) denotes theoretical results in a representative idealized estuary: a) salt-water intrusion length, b) salt-water volume, c) corrective river flow rate. (Krvavica and Ružić, 2020)

4. Conclusion

The SLR impacts in highly stratified estuaries have been assessed in the Neretva River Estuary using three different indicators. The results show that the intrusion length, which is the most common indicator, is sensitive to channel geometry, and may become unreliable when the channel bed slope prevents a potential intrusion further upstream. The salt-water volume is a better choice because it accounts also for the rise of the pycnocline and an increase of the total salt content. The corrective river flow rate is the best choice from a practical view – it quantifies the corrective measures needed to mitigate the adverse effects caused by SLR. In conclusion, the standard methodology for assessing SLR impacts, based on the prediction of consequences, should be expanded by quantifying the adaptation and mitigation measures required to restore the baseline conditions.

Acknowledgements

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References

Intergovernmental Panel on Climate Change (2013) Sea Level Change. In Climate Change 2013 - The Physical Science Basis, Cambridge University Press.

Krvavica N, Kožar I, Travaš V, Ožanić N (2017a) Numerical modelling of two-layer shallow water flow in microtidal salt-wedge estuaries: Finite volume solver and field validation, Journal of Hydrology and Hydromechanics, 65, 49–59.

Krvavica N, Travaš V, Ožanić N (2017b) Salt-Wedge Response to Variable River Flow and Sea-Level Rise in the Microtidal Rječina River Estuary, Croatia, Journal of Coastal Research, 33, 802–814.

Krvavica N, Ružić I (2020) Assessment of Sea-Level Rise Impacts on Salt-Wedge Intrusion in Idealized and Neretva River Estuary, Estuarine, Coastal and Shelf Science, 234, 106638.