J. Int. Environmental Application and Science, Vol. 15(1): 9-18 (2020)

Analysis of the Influence of Adriatic Sea Level on Buna River Flow

Elona Abazi*

Institute of Geosciences, Energy, Water & Environment, Tirana Polytechnic University, Tirana, Albania

Received January 11, 2020; Accepted February 20, 2020

Abstract: The water system of Shkodra Lake, Buna River, and Drini River with a total surface area of 19580 km^2, is the largest in Albania and in Adriatic cost of Balkan Peninsula in terms of watershed and water discharge. Buna River has a total length of around 44 km and an average discharge of 680 m^3/s. Around 1.5 km from flowing out of Shkodra Lake, Buna River joins Drini River, and then after meandering in a low land area Buna River discharges into the Adriatic Sea all the waters of the water system. To study the influence of Adriatic Sea level on Buna River flow, a mathematical model is set-up using SOBEK software developed from Deltares Institute, the Netherlands. The mathematical model is based on topographic survey carried out in the study area. Around 400 cross sections are used to represent the riverbed topography of Buna River and lower part of Drini River. Different sea water levels are analysed, and their effect is evaluated along Buna River for a period of low flow and high flow. Mathematical model results indicate that high water levels of Adriatic Sea due to meteorological and astronomic tide affect Buna River water levels until 21.6 km upstream for the period of high flow, and 37.5 km upstream for the period of low flow. Buna River water levels upstream of the junction with Drini River are not affected from the Adriatic Sea levels.

Keywords: *Buna River, water level, mathematical model, tide, upstream*

Introduction

Buna River is part of the water system of Shkodra Lake, Drini and Buna River. This water system is the largest in Albania and also the largest in Adriatic cost of Balkan Peninsula in terms of watershed and water discharge. The water system of Shkodra Lake, Drini and Buna River has a watershed with significant amounts of annual precipitation ranging from 1600 mm to 4000 mm (IHM, 1975). The water system of Shkodra Lake, Drini and Buna River collects the waters from a total surface of 19580 km^2. The drainage area of this water system is extended in different countries such as: Albania, Montenegro, Kosovo, and North Macedonia. Drini River with its branches Kiri and Gjadri has a total drainage area of 14400 km^2. Shkodra Lake has total drainage area of 5180 km^2 (IHM, 1984). All the waters of this water system are discharged into the Adriatic Sea through Buna River bed. Buna River has an average discharge of 680 m^3/s and total length of 44 km. After 1.5 km away from its source out of Shkodra Lake, Buna River has a junction with Drini River. Buna River is a lowland river with a lot of meanders along its course. Before flowing into the Adriatic Sea, River Buna is divided into two branches. One of the branches flows in the territory of Albania and the other one in Montenegro. Figure 1 shows the location of the study area.

In the case of rivers flowing into the sea, sea level fluctuations have an impact on the water flow regime in the lower part of the rivers. Sea level fluctuations occur due to astronomical tides and meteorological tides. The astronomical tide is caused by the gravitational actions of the Moon and the Sun, and the rotation of the Earth. The astronomical tide has a cycle of rising and falling of water sea levels every day. The meteorological tide represents the changes in water level caused by local meteorological conditions. Meteorological phenomena such as wind, barometric pressure, and precipitation can cause an increase in sea water level. The meteorological tide depends on daily or seasonal changes in weather conditions.

In order to study the influence of Adriatic Sea level on Buna River flow, a mathematical model is set-up for the study area based on the topographic survey made from both countries Albania and Montenegro in their national coordinate systems.

*Corresponding: E-Mail: abazielona2000@gmail.com; Tel: 00355692664303; Fax: 00355042259540

Figure 1. Location of the study area (*Source: Google Streets)*

Materials and Methods

The mathematical model built in SOBEK software is used to study the influence of Adriatic Sea level on Buna River flow. This software is provided in the framework of IPA Cross border Albania-Montenegro project. SOBEK software is developed from the Deltares Institute in Delft, Netherland. This software is designed to perform one-dimensional hydraulic calculations for a full network of natural or constructed channels, and also 2Dimensional hydraulic calculations on two-dimensional (2D) horizontal grids (Deltares, 2013). SOBEK is based on high performance computer technology that means it can handle water networks of any size - big or small. In order to build the mathematical model for the water system of Shkodra Lake, Drini and Buna River, the 1DFLOW module in SOBEK is applied. The 1DFLOW module consists of a network of reaches connected to each other at connection nodes. In each reach a number of calculation points are defined. These calculation points represent the spatial numerical grid to be used in the simulation (Deltares, 2013).

Model equations for 1Dimensional flow

The water flow is computed in SOBEK software by solving the full 1Dimensional Saint-Venant equations. These equations are derived from the Navier–Stokes equations. The 1D Saint-Venant equations are derived from equations of conservation of mass (Eq.1) and conservation of momentum (Eq.2) (Cunge, *et al.,* 1980). The Saint-Venant equations expressed in their non-conservative form are as follow:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (uh)}{\partial x} = 0 \quad \text{[Eq.1]}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial \zeta}{\partial x} + c_f \frac{u|u|}{h} = 0 \quad \text{[Eq.2]}$$

where: ζ water level (with respect to the reference level) defined as $\zeta = h + z_b$ [m]
h local water depth [m]
z_b the local bottom level [m]
u flow velocity [m/s]
c_f friction coefficient

In SOBEK software the Saint-Venant equations are solved numerically using a robust numerical scheme proposed by Stelling called Delft Scheme. This scheme solves the continuity and momentum equation by means of a staggered grid and implicit integration scheme. In this staggered grid the water levels are defined at the connection nodes and calculation points (1D nodes), while the discharges are defined at the intermediate reach segments (Deltares, 2013). The momentum equation and continuity equation will be solved numerically on this grid, which results in the hydraulic states at the calculation points and the reach segments. According to Stelling and Duinmeijer (Stelling & Duinmeijer, 2003), in the case of gradually varied flow or in flow expansion, the momentum conservation equation is applied, whereas for strong flow contraction the energy head formula should be applied.

Setting up the Mathematical Model in SOBEK

The 1D mathematical model using SOBEK software is set-up based on the digital terrain model developed from the topographic survey made in the study area during the period 2005-2006, from the Albanian Academy of Sciences and the Academy of Sciences and Arts of Montenegro (ASA & AASM, 2006). The topography survey was carried out for around 400 cross sections in Buna River and lower part of Drini River (1 Km before the joining with Buna River). Cross sections are measured at intervals of around 100 m from each–other, which gives a good representation of river bathymetry. The mathematical model built in SOBEK software for the water system of Lake Shkodra Lake, Drini and Buna River is presented in Figure 2.

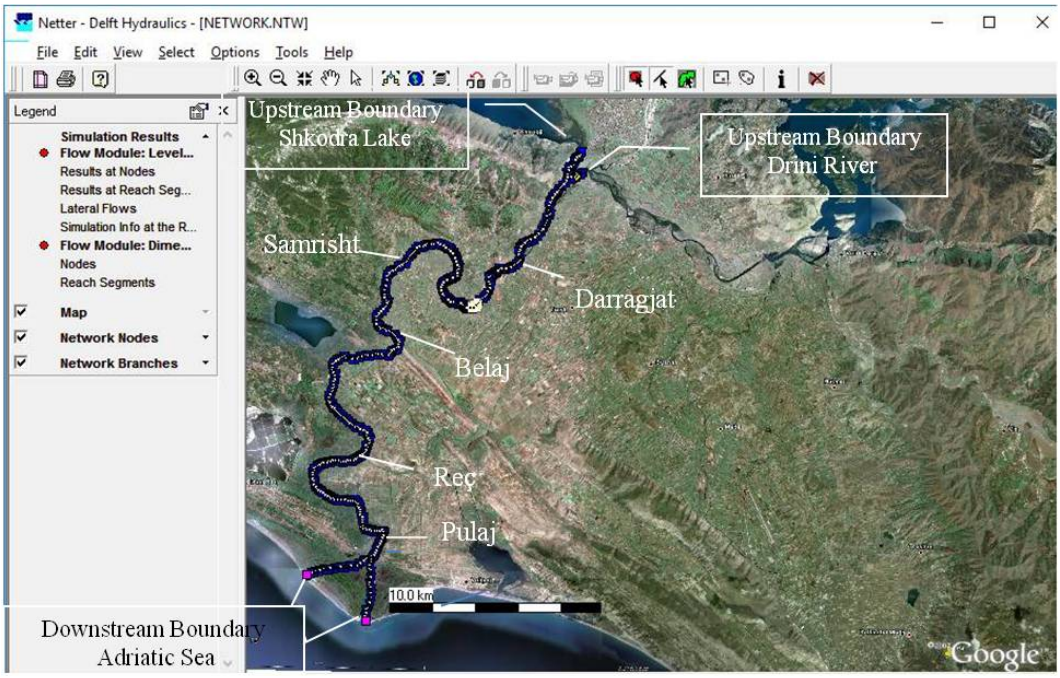

Figure 2. The 1D mathematical model built in SOBEK software for the study area

One of the major steps in setting up a mathematical model is entering the cross section data. For this reason, it is very important to have available a large number of cross sections to describe the geometry of the river system. The quality of the mathematical model depends on the accuracy of the terrain data. Another important element, which describes the river cross sections, is the roughness coefficient. For the river cross sections in SOBEK, which are Y-Z profiles, are used different roughness coefficients for the left overbank, main channel, and the right overbank. Figure 3 represents Manning's *n* values for a given cross section in SOBEK.

Roughness coefficient values for the main channel (n_1) and for the overbank area (n_2) are given preliminary values based on tables and figures compiled by Ven Te Chow (1959). During the calibration process different values of Manning roughness coefficient n_1 and n_2 are tested. The calibration of the mathematical model built in SOBEK software it is accomplished using the traditional method of Trial-and-error (Vidal *et al.,* 2007). For the calibration of the mathematical model hourly data of water level measurements form the Dajç on-line station were used. After the calibration process, the roughness coefficient values which give the best match between the measured water levels and model outputs are accepted.

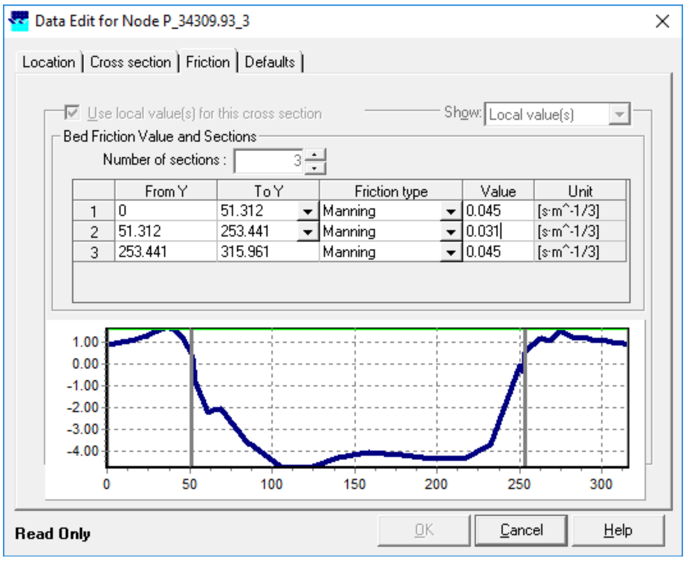

Figure 3. Representation of roughness coefficient for the model built in SOBEK

Results and Discussions

Buna River flow is influenced by the fluctuations of the Adriatic Sea levels. In order to analyse the impact of the Adriatic Sea levels on Buna River flow, average sea levels due to meteorological tide of 0m, 0.5 m, 1.0 m and 1.5 m are considered. The values of average sea level are based on the data of meteorological tides from the observations (IHM, 1984). The study area experiences semidiurnal astronomic tides, which have a cycle with two nearly equal high tides and low tides every day. The astronomic tide has amplitude of 40 cm based on the observations (IHM, 1984). The values of semidiurnal astronomic tides were superimposed to the values of mean sea level from meteorological tide. The effect of Adriatic Sea levels on Buna River regime is analysed for the cross sections in the vicinity of the villages: Pulaj, Reç, Belaj, Samrisht, and Darragjat presented in figure 2.

The mathematical model built in SOBEK software was used to analyse the effect of Adriatic Sea water level on Buna River flow for the period of low flow (5- 18 November 2014) and high flow (25 January-27 February 2015). The inflow (discharge) hydrographs at Buna Bridge (River Buna) and Bahçellëk Bridge (Drini River) for the selected periods are used as upstream boundary conditions (figure 4 and 5). The inflow hydrographs at Buna Bridge used in the 1D model built in SOBEK takes into account the flows coming out of Shkodra Lake into the Buna River. Whereas the inflow hydrographs at Bahçellëk Bridge takes into account the flows coming into Buna River from Drini River. Drini River is a tributary of Buna River, but with a strong influence on Buna River flow. The water flow regime of Drini River, at the downstream part before the junction with Buna River is influenced from the operation of the Vau Dejës hydropower. The discharge hydrographs are calculated based on hourly water level measurements at Buna Bridge and Bahçellëk Bridge stations. Hourly water level measurements at these stations are converted into discharges based on the stage–discharge relationship. Stage–discharge relationship is created based on discharge measurements done in Buna Bridge and Bahçellëk Bridge for the period 1992-2001, and 2010 (GIZ, 2018). As downstream boundary condition it is used the hydrograph of sea water level at Buna River mouth in Albanian and Montenegro for the values: ± 0 m, ± 0 m and tide 40 cm (± 0.2 m), 0.5 m and tide 40 cm (± 0.2 m), 1.0 m and tide 40 cm (± 0.2 m), 1.5 m and tide 40 cm (± 0.2 m).

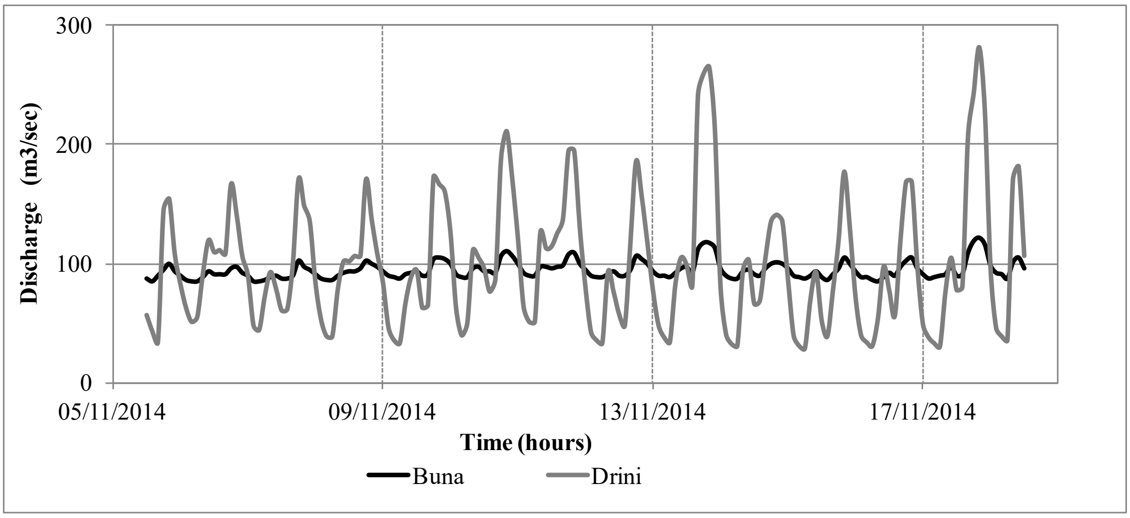

Figure 4. The inflow hydrographs at Buna and Drini River for the low flow period

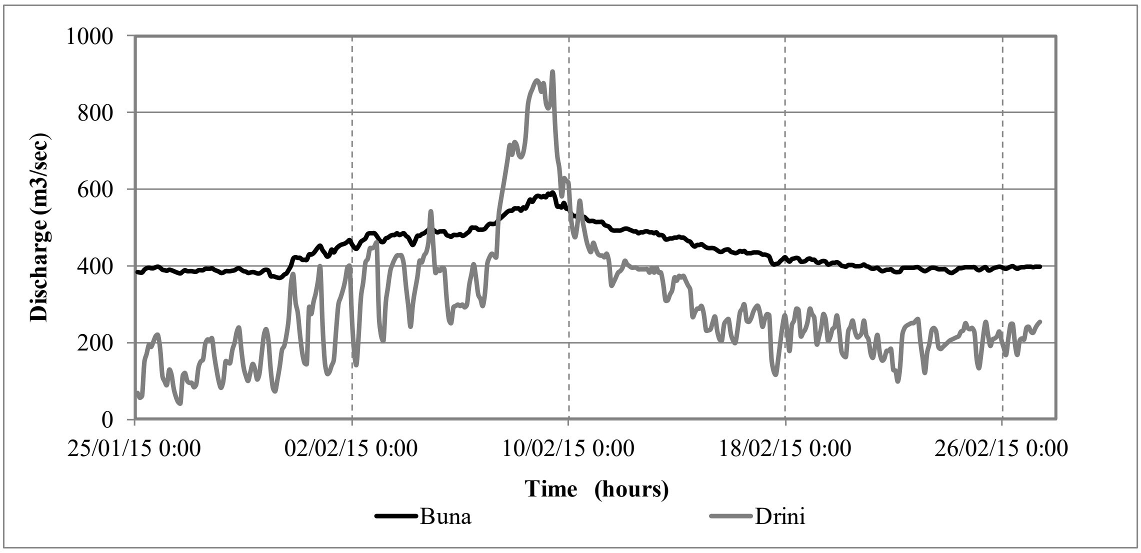

Figure 5. The inflow hydrographs at Buna and Drini River for the high flow period

Impact of Adriatic Sea level on Buna River for the period of low flow

The fluctuations of water levels along Buna River for the period of low flow (5- 18 November 2014) are based on mathematical model results for the study area. Adriatic Sea water level effects are analysed for the cross sections along Buna River in the vicinity of the villages: Pulaj, Reç, Belaj, Samrisht, and Darragjat at respectively distance from the sea (3.4 km, 11.6 km, 21.6 km, 27 km, and 37.5 km).

The figures 6 to 10 show that Adriatic Sea level fluctuations have an impact on the flow regime of Buna River for the period of low flow. The impact is very significant in the profile close to Pulaj village, where Buna River water levels follow the sea level fluctuations. At the profile close to Reç village the impact is still strong, Buna River water level follow the sea level fluctuations especially for high sea water levels. The impact of sea level fluctuations starts to decrease at profile close to Belaj and Samrisht village. At the profile close to Darragjat village the impact of sea level fluctuations on Buna River water levels is small, even in the case of high sea water levels. Water levels of Buna River are not affected from sea level fluctuations for the profiles upstream of Darragjat.

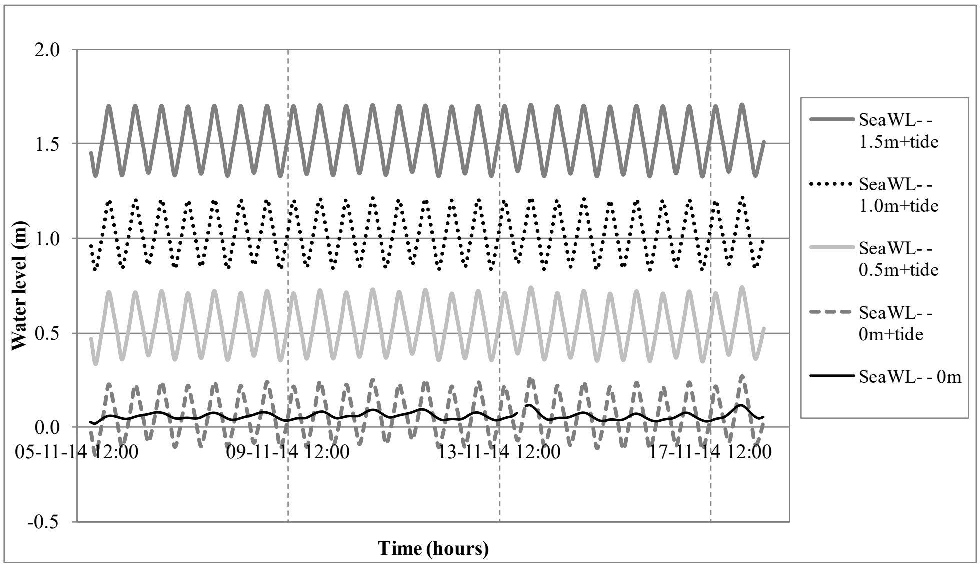

Figure 6. Water level close to Pulaj for different sea level for the low-flow period

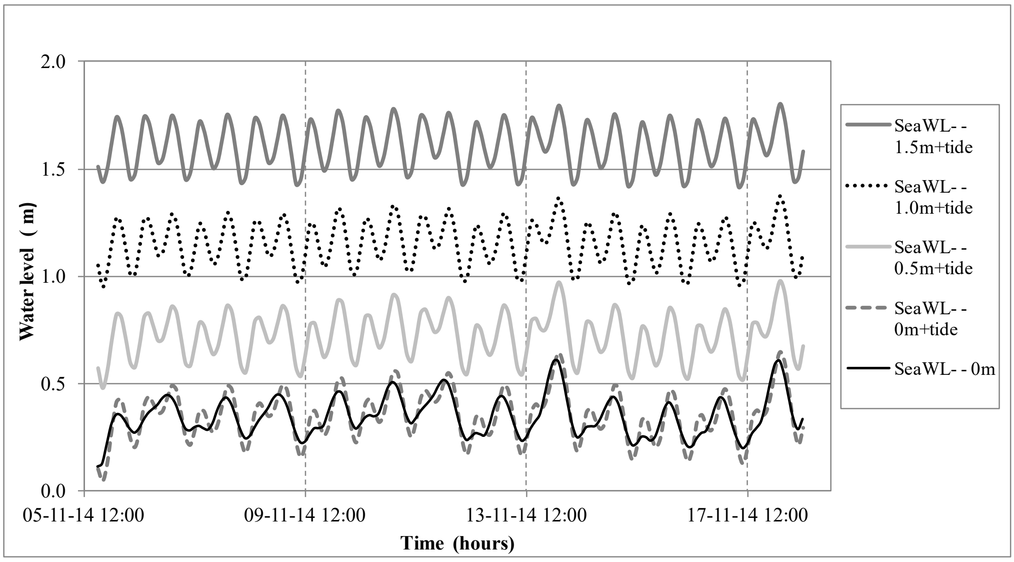

Figure 7. Water level close to Reç for different sea level for the low-flow period

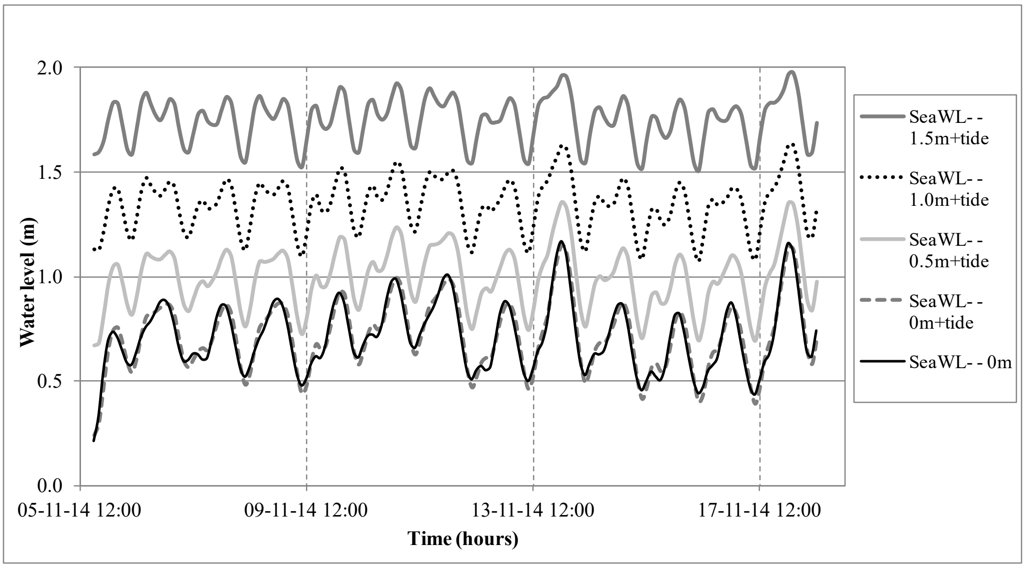

Figure 8. Water level close to Belaj for different sea level for the low-flow period

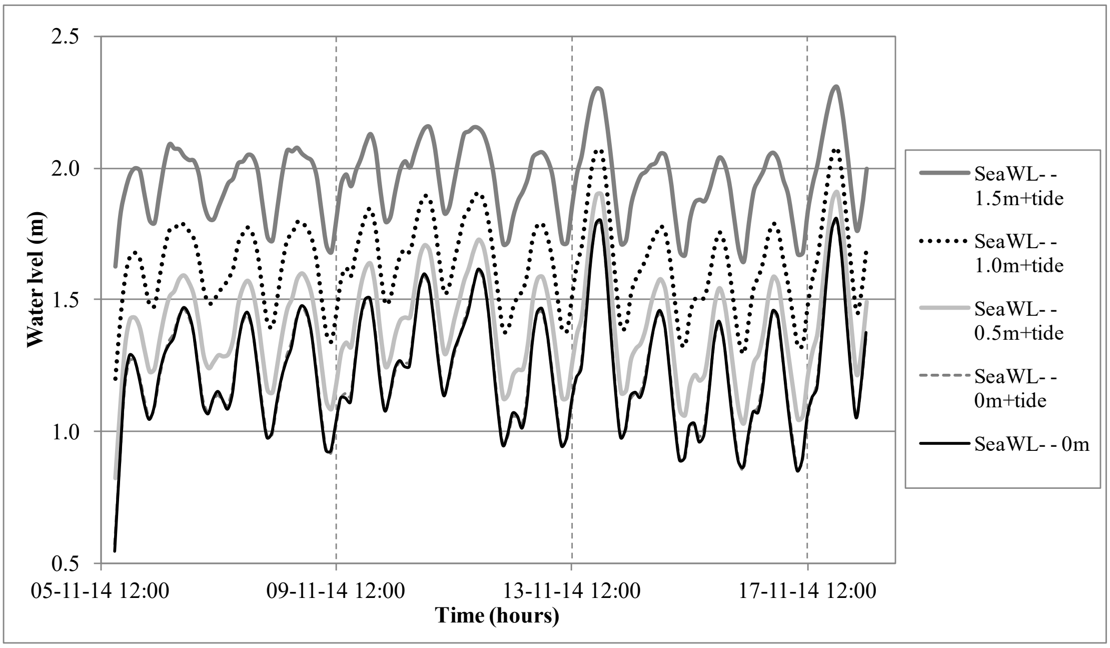

Figure 9. Water level close to Samrisht for different sea level for the low-flow period

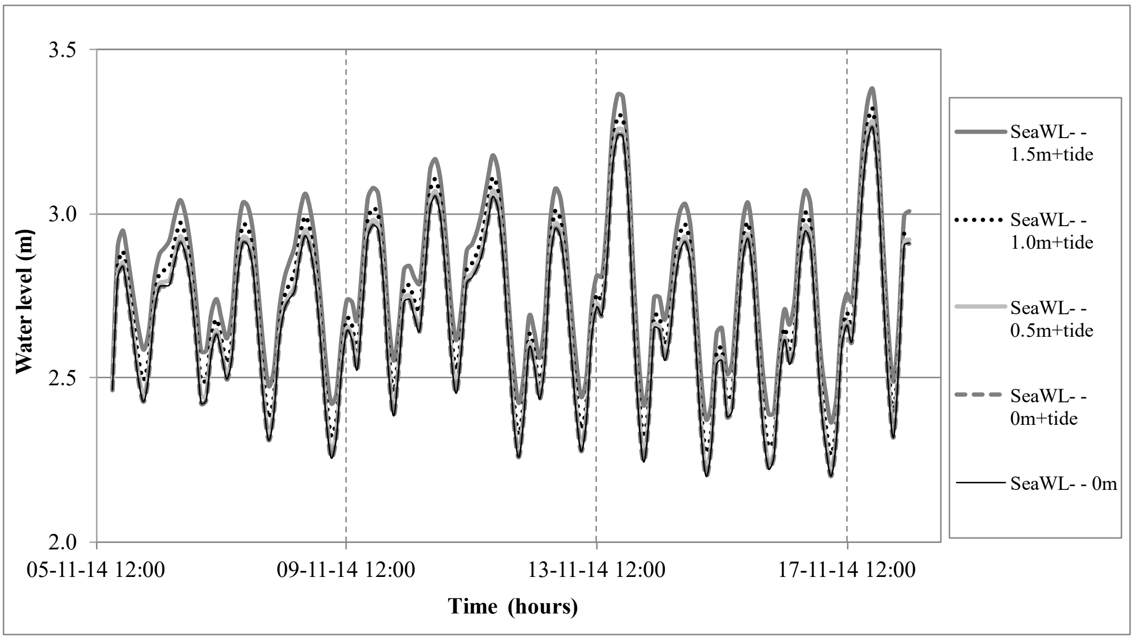

Figure 10. Water level close to Darragjat for different sea level for the low-flow period

Impact of Adriatic Sea level on Buna River for the period of high flow

The following figures 11, 12, 13, 14, and 15 show the fluctuations of water levels for the period of high flow (25 January -27 February 2015) based on mathematical model results. Adriatic Sea water level effects are analysed for the cross sections along Buna River in the vicinity of the villages: Pulaj, Reç, Belaj, Samrisht, and Darragjat at respectively distance from the sea (3.4 km, 11.6 km, 21.6 km, 27 km, and 37.5 km).

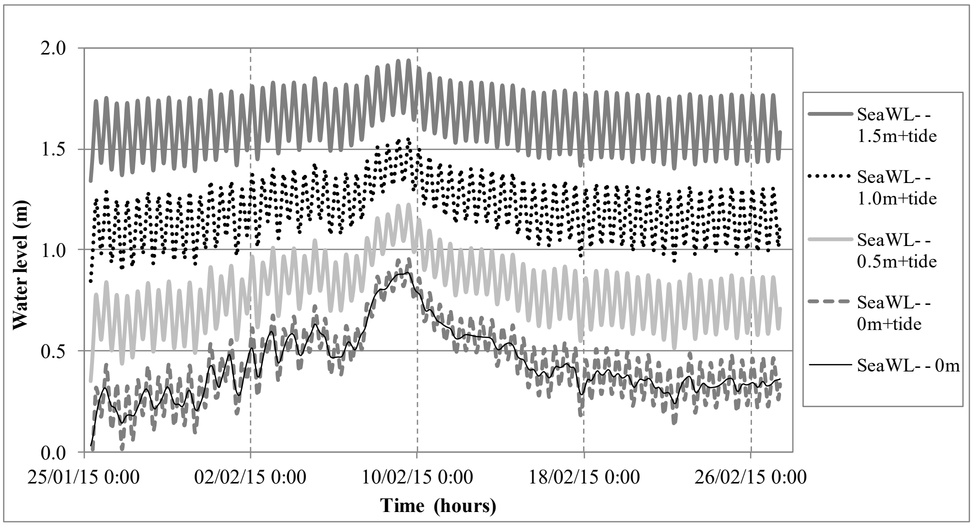

Figure 11. Water level close to Pulaj for different sea level for the high-flow period

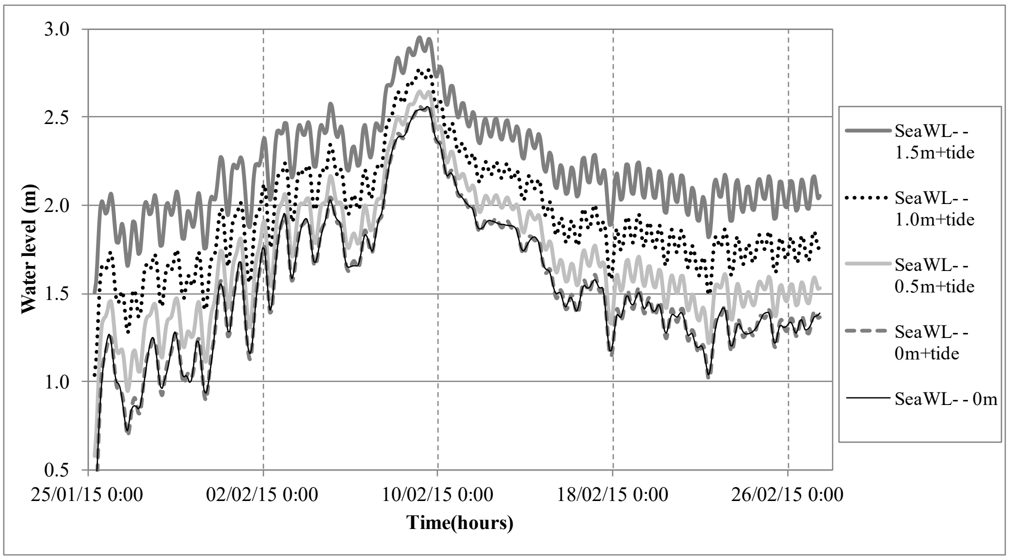

Figure 12. Water level close to Reç for different sea level for the high-flow period

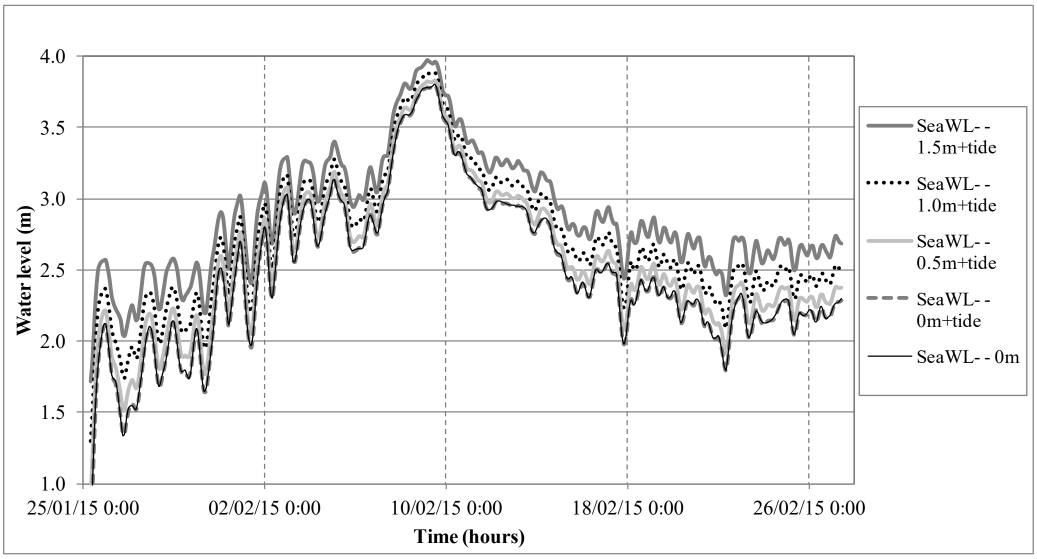

Figure 13. Water level close to Belaj for different sea level for the high-flow period

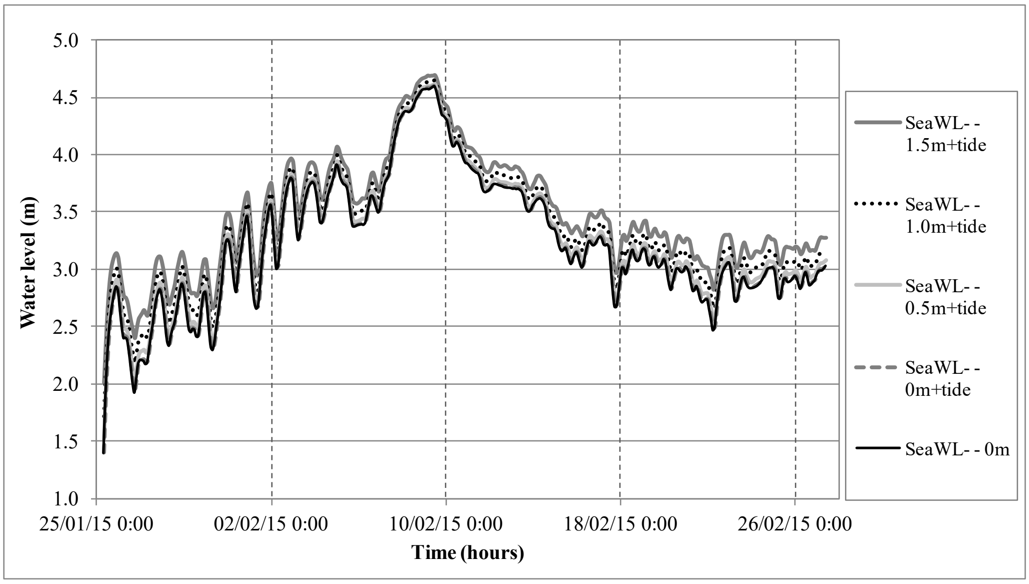

Figure 14. Water level near Samrisht for different sea level for the high-flow period

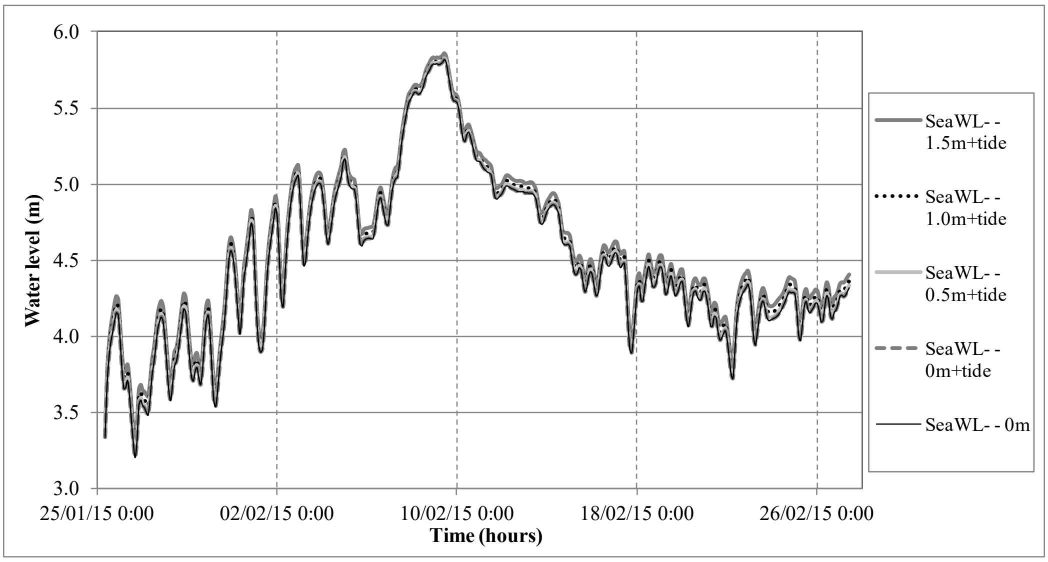

Figure 15. Water level near Darragjat for different sea level for the high-flow period

From the above figures 11 to 15, we can see that for the period of high flow, water level at profile close to Pulaj village follow the Drini River fluctuations superimposing the effect of the sea level fluctuations. At the profile close to Reç village, Buna River water levels follow the fluctuations of Drin River superimposing the effect of sea level fluctuations, but in a smaller degree than in Pulaj. At the profile close to Belaj and Samrisht, water levels of Buna River follow the fluctuations of Drin River superimposing the effect of sea level fluctuations, especially for high sea water levels. At the profile close to Darragjat village only high sea water levels have a small impact on Buna river water levels. Water levels of Buna River are not affected by the sea level fluctuations for the profiles upstream of the junction with Drini River.

Conclusions

The impact of the Adriatic Sea levels on Buna River flow is analysed through a mathematical model built in SOBEK software for average sea levels of meteorological tide 0 m, 0.5 m, 1.0 m, and 1.5 m. The values of astronomic tide with amplitude of 40 cm were superimposed to the values of mean sea level from meteorological tide.

Mathematical model results indicate that the increase of Adriatic Sea level due to meteorological and astronomic tide leads to the increase of Buna water levels for the period of high flow, and especially low flow. The effect of Adriatic Sea level on Buna River flow can reach many kilometres upstream because of low bottom slope of Buna River.

- For average sea level of 0.0 m plus the astronomic tide 40cm the impact on Buna River water levels can reach upstream until Reç for the period of low flow. Maximum increase of Buna water level for this period near Reç is 9 cm. For the period of high flow the impact on Buna River water levels can reach upstream until Pulaj, where the increase of Buna water level for the peak event is 7 cm.
- For average sea level of 0.5 m due to meteorological tide plus the astronomic tide 40 cm the impact on Buna River water levels can reach upstream until Samrisht for the period of low flow. Maximum increase of Buna water level for this period near Samrisht is 20 cm. For the period of high flow the impact on Buna River water levels can reach upstream until Belaj, where the increase of Buna water level for the peak event is 5 cm.
- For average sea level of 1.0 m due to meteorological tide plus the astronomic tide 40cm the impact on Buna River water levels can reach upstream until Darragjat for the period of low flow and high flow. Maximum increase of Buna water level for the period of low flow is 7 cm. For the period of high flow the increase of Buna water level in Darragjat for the peak event is 2 cm.
- For average sea level of 1.5 m due to meteorological tide plus the astronomic tide 40 cm the impact on Buna River water levels can reach upstream until Darragjat for the period of low flow and high flow. Maximum increase of Buna water level for the period of low flow is 17 cm. For the period of high flow the increase of Buna water level in Darragjat for the peak event is 4 cm.

The Adriatic Sea level fluctuations do not affect the flow of Buna River upstream of the junction with Drini River. Buna River water level fluctuations upstream of the junction are affected from the Drini River fluctuations caused from the operation of the Vau Dejës hydropower.

References

IHM, (1975) Academy of Science of Albania, *Climate of Albania*. Institute of Hydro-Meteorology of Albania.

IHM, (1984) Academy of Science of Albania, *Hydrology of Albania*. Institute of Hydro-Meteorology of Albania.

Deltares, (2013) *SOBEK User Manual*, Version 2.13. https://www.deltares.nl, Delft, The Netherlands.

Cunge JA, Holly FM, Verwey A, (1980) *Practical Aspect of Computational River Hydraulics*. Pitman Advanced Publishing Program, London. UK.

Stelling GS, Duinmeijer SP, (2003) A staggered conservative scheme for every Froude number in rapidly varied shallow water flows. *Int. J. Num. Meth. Fluids*, **43**, 1329-1354.

ASA & AASM, (2006) *Topo-geodetic Measurements of Buna River*. Joint Project of Academy of Sciences of Albania and Academy of Sciences and Arts of Montenegro.

Chow VT, (1959) Open Channel Hydraulics. McGraw-Hill Book Co. New York, USA.

Vidal JP, Moisan S, Faure JB, Dartus D, (2007) River model calibration, from guidelines to operational support tools. *Environ. Model. & Software*, **22**(11), 1628-1640.

GIZ, (2018) *Climate Change Adaptation in Transboundary Flood Risk Management*, Western Balkans (CCAWB II). German Federal Enterprise for International Cooperation.