Digital Terrain Modeling Of The Buna River System And Of The Northwestern Flood Plain In Albania

Sh. Kuka, E. Begu, T. Myftiu, E. Abazi

Abstract: Excessive rains in the Shkodra Lake and the Drin River basins, and mandatory discharges from the Drin cascade dams, often cause extensive flooding in the northwestern regions of Albania, with many houses, roads and other infrastructure affected. Negative impacts of primary concern are dangerousness for loss of human life, economic loss including property damage, lifeline disruption and environmental damage. Inundation hazard downstream of dams is a critical problem, observed especially during the period December 2009-January 2010. In order to support the hydraulic investigations and the project development for the prevention and reducing the flooding damages, two digital elevation models are built. The first one characterizes the Buna River watercourse, from the Shkodra Lake till the exit sea. It is built using the topographic survey of the Buna riverbanks, and the bathymetric measurements of its watercourse bed profiles. The model will be used mainly to compute the water surface profiles for various pluvial scenarios and various water discharges from the Drin River cascade. The second DTM model is built based on the integrated digital database which includes the topographic and bathymetric surveys undertaken jointly by the Albanian and Montenegrin project teams during the period 2005-2006, and the digital topographic maps of the scale 1:10,000 for a vast flat area downstream the last dam on the Drin cascade. Intention was to support simulation of the water wave spreading, water management scenarios, and flooding damage analysis in this wide and very productive area region.

Index Terms: rainfall, floods, topographic and bathymetric survey, datum transformation, DTM.

1 Introduction

Albania is located at the boundary of two climatic regions: the Mediterranean zone, and Central Europe. In addition, the country combines a coastal plain in the West with fairly high mountains: the highest point reaches 2751 m at the triple border with Kosovo and Macedonia, while many ridges exceed 2000 m in the northern, central and southern parts of the country. The rain comes mainly with south-west winds and falls according to the obstacles encountered. Average annual rainfall is around 1485 mm; the seasonal pattern is very December, as the wettest one. The most important cause of floods is excessive rain. Rain may be seasonal occurring over wide areas, or from localized storms which produce the highest intensity rainfall. Melting snow is another major contributor to floods. The floods, in general, have a pluvial origin and so they are observed during the period of November-March, when it flows 80-85% of the annual runoff. The floods are flashy and in the main rivers they traverse the hydrographic network in 8-10 hours. During the big floods the water overflow in the Western Plain of Albania, creating almost one river mouth.

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a total area of 19,582 km² from which 14,173 km² belong to the Drin itself and 5,187 km² to the Buna River. The Buna River is the one that drains Shkodra Lake. This lake is fed by rivers originating from Montenegro and Albania; its larger tributary is Moraça which materializes the border. In the past the exits to the Sea of Buna and Drin River have been separated. Nowadays, the old bed of the Drin that leads south to the city of Lezhe carries only a minor part of the discharge; the rest meets the Buna near Shkodra and follows its river bed along the border with Montenegro. The Drin River has a mean annual discharge of 680 m³/s for the period 1951-1985, of which 360 m³/s come from the Drin River itself and 320 m³/s from the Buna River. The resulting specific discharge is about 35 l/s km² and the runoff coefficient is 0.74. But these high values are mainly due to the very high yield of the Buna River, which cannot be much exploited - except for navigation. The most important river in the catchment is the Drin River, with the following characteristics (SECO 2006):

- Annual discharge volume: 11,100 million m3
- Specific discharge: 24.8 l/s km²
- Ratio wettest month (December) to driest month (August): 5.7
- One in 10 year high flow: about 13 times the river module.

The Drin River cascade is situated in the north-eastern part of Albania. It consists of three hydro power plants with three high dams, namely Fierze (height 170 m), Koman (100 m) and Vau i Dejes (46.4 m height). The reservoir created by the Fierze dam, with a total storage of 2’700 million m3, serves as head reservoir for the Drin River cascade. Downstream from Vau Deja dam, the Drin River runs through a flat landscape plain till meets the Buna River, originating from the Shkodra lake, about one km southwest of the Shkodra city, and then continue to flow through a very flat area till the Adriatic Sea exit.

Fig. 1. Satellite image of the Drin and Buna rivers and the northwestern flood plain: 1) Komani dam, 2) Vau-Deja dam, 3) Shkodra town, 4) Shkodra Lake, 5) Drin River, 6) Buna River.

Fig. 2. Inundation map downstream of Vau-Deja HPP (produced on January 9, 2010 by *Center for Satellite Based Crisis Information:* http://www.zki.dlr.de).

Dams are innately hazardous structures. Failure or faulty operation can result in the release of the reservoir contents causing negative impacts upstream or downstream of the dam. Negative impacts of primary concern are loss of human life, economic loss including property damage, lifeline disruption and environmental damage. Especially in the west flood plain of the Drin River the population density is in the range between 50 to more than 1’000 inhabitants per sq km. Most of the settlements are in the range between 500 – 5’000 inhabitants. City of Shkoder has more than 100’000 inhabitants. These areas are highly affected in case of a large precipitation in the Drin River basin. In total, there are about 300'000 people at risk. The studies (SECO, 2006) show the consequences would be catastrophic, in case of any dam break in the Drin River cascade. A break of one of the dams would release an incredible amount of water downstream (more than 2.75 billion cubic meters), and that because of the gain in velocity of this water given by the head difference, the level of damage would be a much worst disaster than that of New Orleans in 2005. Inundation hazard downstream of dams is a critical problem, observed especially during the period December 2009-January 2010. The inundation map of January 2010 is presented in the Figure 2. The main problem is the northwestern flood plain, due to the insufficient discharge capacity to absorb major floods generated from the intensive precipitation and the draw released by the spillways of Vau-Deja dam. This is a general river engineering problem, which is not caused by the hydro power stations. Therefore, it is very important undertaking of hydraulic investigations to support the project development for the prevention and reducing the flooding damages in this region.

3. Build-up the DTM for Buna River and the northwestern flood plain

Excessive rains in the Drin river basin or large discharges from the Vau-Deja dam often cause extensive flooding, with many houses, roads and other infrastructure affected. Flooded towns and places include the Shkodra city and many other settlements downstream of this dam. Inundation hazard in the West flood plain of the Drin and Buna rivers is a general river engineering problem, which is not caused by the hydro power stations. However, to avoid the potential consequences of a failure of dams of the Drin River cascade, large water discharge from the relevant reservoirs in the case of excessive rains are an obligate action, and this further aggravates the flooding situation downstream the Vau-Deja dam. In order to calculate the water levels and the direction of propagation of the flood waves in the very extensive and flat area downstream the Vau-Deja dam, a detailed Digital Elevation Model (DTM) is an indispensable precondition for hydraulic investigations and performance of a wave spreading simulation. This will support the decision-making and undertaking the adequate engineering measures for the prevention and reducing the flooding damages.

3.1 The digital database

In the period 2005-2006, in the frame of an agreement between Academy of Science of Albania and the Academy of Art and Science of Montenegro, were accomplished the joint topographic and bathymetric works for measuring the coastal profiles and the profiles of the watercourse bed of the Buna River from the exit of the Shkodra Lake to the estuary of the Adriatic Sea, in total 42 km length (ASA & AASM, 2006). Geodetic measurements were carried out also on the Drini River from the estuary of Buna River in longitude 1 km, as well as a part of the Shkodra Lake including the exit of the Buna River (Figure 3). Recently, in the frame of National Programs for Research and Development, an important project on the “Hydro-regime regulation of Shkodra Lake, Drini and Buna River’s Water System” is launched. An essential integrated component of this project is building of a Digital Terrain Model (DTM) for a vast area that comprises Shkodra Lake and other surroundings which are affected from the outlet of Drini River on Vau i Dejes and Buna downstreams. In order to successfully accomplish this task, we are based on the following information sources:

1. Bathymetric and topographical survey on study area during 2005-2006, performed from Academy of Science of Albania and Academy of Art and Science of Montenegro.
2. Topographical maps of the area on scale 1:10.000.
3. Aerial photos and satellite images of the study area.

43 sheets of the scale 1:10 000, covering an area of about 80 km2, are scanned and georeferenced into Albanian coordinate system. The project team digitized carefully the existing contour lines and the spot heights, so the relevant DTM model embodies the accuracy of the original official topographic maps. This work enabled compilation of a solid digital database on the terrain, buildings and infrastructure objects, the watercourses and the existing drains, thus providing the necessary preconditions to analyze the existing drainage network and protection levees, as well as design of the new protection structures diverting storm waters from the flat plain to the sea.

3.2 Data transformation into UTM-34 (WGS-84)

The above mentioned information sources were in different coordinate systems. The Montenegro project team has performed the topographical survey based on national Montenegrin coordinate system, while the data offered by Albanian project team are in the old national coordinate system, locally known as Alb86 (local projection: Gauss-Krueger, Zone 4 (6°); Datum: S-42). The topographic maps of the scale 1:10,000 are also in the Alb86 coordinate system.

Fig. 3. Geodetic works (magenta) accomplished during 2005-2006

TABLE 1.
TRANSFORMATION PARAMETERS FOR ALBANIA

Source ellipsoid: GRS80		
	a=6378137 m	f=0.003352811
Target ellipsoid: Krassovsky		
	a =6378245 m	f=0.00335233
Helmert parameters:		
	tx =	-44.183 m
	ty =	-0.580 m
	tz =	-38.489 m
	rX =	-0° 00' 02.3867"
	rY =	-0° 00' 02.7072"
	rZ =	0° 00' 03.5196"
	s =	-8.2703 ppm

Hence, in order to build up the DTM, the first task to be attained was to convert all the available data in a common coordinate system that is WGS-84 (UTM-34). To convert between datums, a 'Helmert transformation' is used:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}^B = \begin{bmatrix} tx \\ ty \\ tz \end{bmatrix} + \begin{pmatrix} 1+s & -r_Z & r_Y \\ r_Z & 1+s & -r_X \\ -r_Y & r_X & 1+s \end{pmatrix} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix}^A$$

Here (x,y,z) A and (x,y,z) B are the Cartesian (geocentric) coordinates, in the datums A and B respectively.The conversion into WGS84 (UTM-34) of geodetic measurements taken by Albanian team, and of the digital maps of the scale 1:10.000, was performed based on the related Helmert transformation parameters (Table 1), derived from a common study between Geographical Military Institute of Firenze (Italy) and Geographical Military Institute of Albania, completed in 2008 (ALBACO, 2008). The bathymetric data and the related files delivered from the Montenegrin project team were in national Montenegrin coordinate system (MGI/Balkans, Zone 6). The Militärgeographisches Institute "MGI / Balkans" coordinate system is the Gauss-Krueger-based coordinate systems, which has been in use since 1920's. Figure 4 illustrates the division of the ex-Yugoslavia territory in Gauss-Krueger zones of 30. The transformation into WGS-84 of geodetic measurements taken by the Montenegrin project team was attained based on appropriate related Helmert transformation parameters (MGI/Balkans Coordinate Systems - http://spatial-analyst.net). These parameters are presented on Table 2.

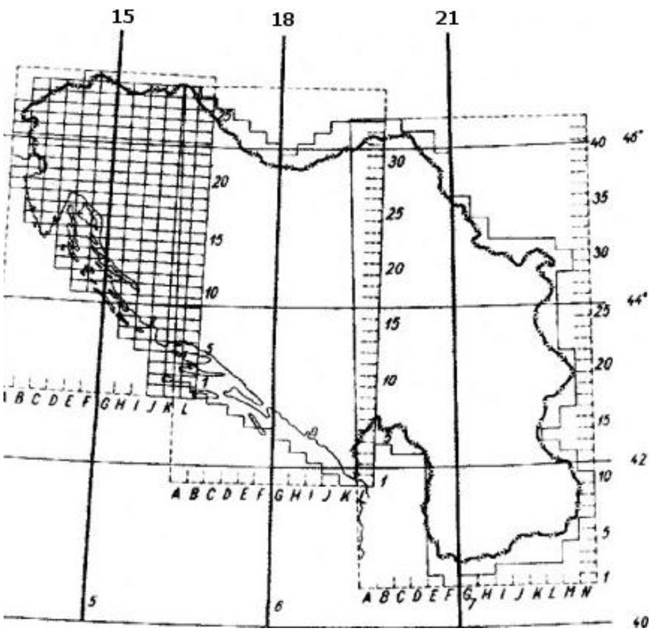

Fig. 4. The division of the ex-Yugoslavia territory in Gauss-Krueger zones of 30.

Conversion into projection UTM-Zone 34 North (Datum: WGS-84) of the geodetic measurements taken in 2005-2006 by the Albanian and Montenegrin project teams, and of the topographic maps of the scale 1:10000, is accomplished using the above mentioned Helmert transformations and the relevant software developed by us. The procedure followed is:

1. Convert projection coordinates (E, N, H) to ellipsoidal coordinates (φ,λ, h), using the relevant projection parameters (Alb86 for Albania, and MGI-6 for Montenegro).
2. Convert ellipsoidal coordinates (φ,λ, h) to Cartesian coordinates (x,y,z), using the corresponding ellipse parameters (Soler and Hothem, 1988).
3. Apply the relevant 7-parameter Helmert transformation (1) to WGS-84 datum; this applies a 3-dimensional shift, rotation, and scale.
4. Convert Cartesian coordinates back to ellipsoidal, using the WGS-84 ellipsoid (Soler and Hothem, 1988).
5. Convert WGS-84 coordinates to UTM, zone 34.

The vertical reference used in this study should be the Albanian system of orthometric heights, which means the Albanian local orthometric level of Adriatic Sea with “zero” origin – the mareograph of Durres. The geodetic measurements taken by the Montenegrin team are calculated on the Levelling System of Montenegro, with “zero” origin – the mareograph of Bar (Adriatik Sea). A detailed investigation (ASA & AASM, 2006) shows that the vertical datum of Albania is 9.2cm higher than the vertical datum of Montenegro. Therefore, to all the Montenegrin project data was performed an additional height transformation, increasing the relevant elevations with 0.092 m, in order to convert them into the Albanian system of orthometric heights.

3.3 Build up of DTM

Based on the above data, two digital terrain models (DTM) were built up. The first one characterizes the Buna watercourse, from the Shkodra Lake till the exit sea. It is built using the topographic survey of the Buna riverbanks, and the bathymetric measurements of its watercourse bed profiles. Because of lack of the data, modeling has not been undertaken along the Drini River, from joining in the Buna River up to the Vau-Deja dam. The model will be used mainly to compute the water surface profiles for various pluvial scenarios and various water discharges from the Drin River cascade. The accuracy of the modeling of the Buna riverbed and its riverbanks, from the river-head to the sea is restricted by the limited detail of the available geodetic measurements, and the results presented here are therefore associated with some uncertainty. However, this model can be used mainly in the feasibility stage of the projects related with the flood protection and the safe navigation on the whole flow of the Buna River. For the design stage, additional topographic measurements along the riverbanks and a dense bathymetric survey along the riverbed should be undertaken. Downstream of Vau-Deja dam and Shkodra Lake till the Adriatic Sea, where the floodplain is very extensive and flat, another DTM model is built based on the integrated digital database which includes the topographic and bathymetric surveys undertaken jointly by the Albanian and Montenegrin project teams during the period 2005-2006, and the digital topographic maps of the scale 1:10,000. Intention was to support simulation of the water wave spreading, water management scenarios, and flooding damage analysis in this wide and very productive area of more than 9000 ha. A general view (ArcGIS scene) of this DTM is shown in the Figure 5.

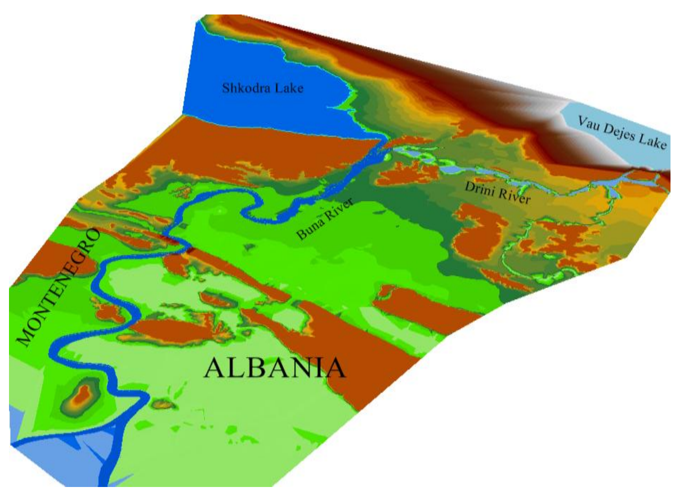

Fig. 5. View of the DTM model for the region downstream the Vau-Deja dam.

The digital terrain model of the Buna river system and the integrated digital terrain model for the northernwest flood plain are provided in ArcInfo TIN format. They can be used to prepare the geometric data for import into any software for river analysis systems (HEC-RAS), and in the further GIS analysis for floodplain mapping, flood damage computations, ecosystem restoration, and flood warning response and preparedness. These DTM models are designed to assist the project study members for formulating and evaluating flood risk management measures.

4 Conclusions

Heavy rains in the Shkodra Lake and the Drin River basins, and mandatory discharges from the Drin cascade dams, often cause extensive flooding in the northwestern regions of Albania. Negative impacts of primary concern are distress for loss of human life, economic loss including infrastructure and property damage, lifeline disruption and environmental damage. Inundation hazard downstream the Drin cascade dams is a critical problem, observed repeatedly the last years. In order to support the hydraulic investigations and the project development for the prevention and reducing the flooding damages, digital terrain modeling of the Buna River system and of the area downstream the lowest dam on the Drin cascade is required. Therefore, based on the available data, two digital terrain models were built. The first one characterizes the Buna watercourse, from the Shkodra Lake till the exit sea. It will be used mainly to compute the water surface profiles for various pluvial scenarios and various water discharges from the Drin River cascade. The second DTM model is built based on the integrated digital database which includes the topographic and bathymetric surveys undertaken jointly by the Albanian and Montenegrin project teams during the period 2005-2006, and the digital topographic maps of the scale 1:10,000. All the data are preliminarily converted in a common local projection (UTM Zone 34 North), using the related Helmert datum transformation for Albania and Montenegro. The digital terrain model of the Buna river system and the integrated digital terrain model for the northwestern flood plain are provided in ArcInfo TIN format. They can be used to prepare the geometric data for import into any software for river analysis systems (HEC-RAS), and in the forthcoming GIS analysis for floodplain mapping, flood damage computations, ecosystem restoration, and flood warning response and preparedness. These DTMs will support the decision-making and undertaking the adequate engineering measures for the prevention and reducing the flooding damages.

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