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OVERVIEW OF SPATIAL REFERENCE SYSTEMS FOR HAZARD RISK MANAGEMENT IN THE NE REGION OF ROMANIA

BY

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Abstract. The paper aims to present the general framework of the spatial reference for geoinformation in the NE region of Romania, in order to have a unitary approach to joint cross-border projects with the Republic of Moldova in the field of risk management. Due to the multitude of spatial data sources involved in such projects and the processing of geodetic measurements on different reference surfaces, a distinct presentation of coordinate reference systems is required for horizontal, vertical and spatial positioning. In operating with these coordinate reference systems, there is an implicit need for coordinate conversions and transformations, which must be performed within acceptable precision level, according to the requirements of the project. Therefore, the paper outlines a practical guide in working with spatial data specific to different datums and map projections for this area. In the last part of the paper, the cartographic fund at national level corresponding to the official datums in Romania in the last decades is presented and finally, the framework for defining the spatial reference systems for cross-border projects is proposed.

Keywords: datum; map projection; positioning; conversion; transformation.

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1. Introduction

Hazard risk management involves both isolated phenomena (*e.g.* in landslide monitoring on a slope) that can be highlighted in a singular frame of reference, but also extended phenomena (*e.g.* in highlighting flood areas), which requires a spatial correlation with the entire studied territory. In the latter case, the importance of spatial reference systems in which such projects are carried out is noted and the need to solve a series of problems that arise when data acquisition is made in a reference system, which differs from the one in which they will be express in the end. The causes of these differences are mainly due to the increasing development of Geographic Information Systems (GIS), the widespread use of satellite navigation systems (GNSS) as well as the introduction of web mapping services (Chirilă, 2015). In particular, the need to establish an unique spatial reference system arises as a result of positioning and mapping of the phenomena pursued in the project, by combining digital data between different organizations as part of the collaboration between two neighboring states. The necessary level of accuracy also requires additional studies, such as that of deformations in terms of map projection, with effects on the precision of positioning the geometrical details in the study area (Iliffe and Lott, 2008).

When analyzing the notion of spatial reference system (Jekeli, 2012), the two basic components are taken into account, namely, the datum concept and the coordinate system (Fig. 1).

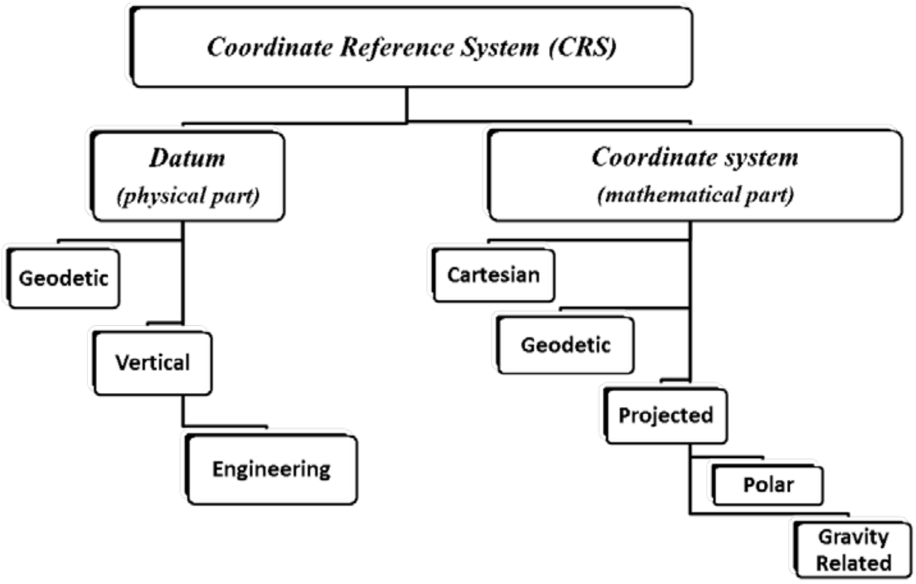

Fig. 1 – Description of the spatial reference (according to ISO-19111).

In the context of the European standard for geographical information (ISO 19111) the technical concept of coordinate reference system (CRS) is used, which is a coordinate system whose position, scale of representation and orientation is defined by association with an object (datum description).

2. Coordinate Reference Systems for Horizontal Positioning

In the classical sense, the establishment of horizontal geodetic networks is performed separately from the vertical ones, based on geodetic datums which are the reference frame for the projection of measurements made on the earth's surface to that of an ellipsoid and then in the plane of the map projection.

The current national triangulation of Romania as well as of other Central and Eastern European states developed on the surface of the Krasovski reference ellipsoid determined in 1940 (Fig. 2). The classical triangulation network has as origin point the astronomical observatory Pulkovo (Russia), hence the name of the datum underlying this network, Pulkovo - 42 (S-42).

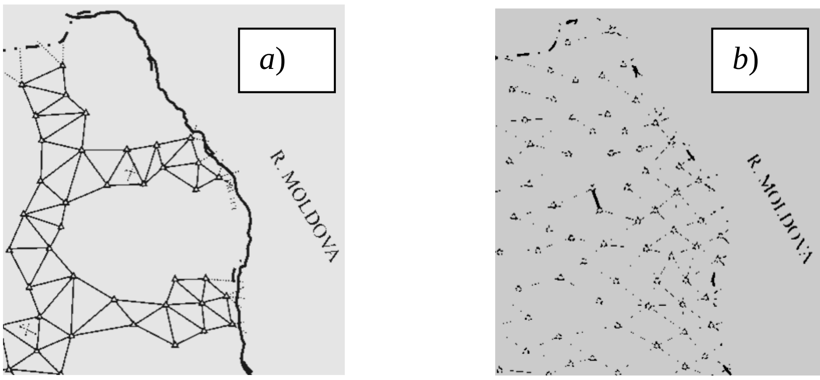

Fig. 2 – First order geodetic triangulation chains (*a*) and first order astronomical-geodetic triangulation network (*b*) in the NE region of Romania (Ghițău, 1983).

After the establishment of the Pulkovo - 42 datum, two conformal map projections were used: the Gauss - Krüger transverse cylindrical projection and the oblique stereographic azimuthal projection - 1970 (Table 1). The Gauss-Krüger projection contributed to the creation of an important map repository, being used in the military sector until 1990, even after the establishment of the stereographic projection - 1970. After Romania's integration into the NATO political and military alliance, the Gauss projection was replaced by the UTM (Universal Transversal Mercator) projection, based on the WGS84 datum (Table 1). In the civil sector, the stereographic projection - 1970 is still kept as a national projection, but with the official acceptance of the European ETRS89 datum, there are proposals to redefine this projection (“Stereo – 2010”) based on the global ellipsoid GRS80 (Chirilă, 2015).

Table 1
Parameters of Map Projections Used in Romania (NE Region)

Parameter	*Gauss-Krüger projection*	*UTM projection*	*Stereo -70 projection*
Latitude of natural (real) origin	φ_o = 0° (the Equator)	φ_o = 0° (the Equator)	φ_o = 46° N
Longitude of natural (real) origin / Longitude of the central meridian	Zone no. 35: λ_o = 27° E	Zone no. 35: λ_o = 27° E	λ_o = 25° E
Scale factor in natural origin / Scale factor at central meridian	K_o = 1	K_o = 0.9996	K_o = 0.99975
False north (value assigned to the natural origin)	X_o = 0 m	X_o = 0 m	$N_o = X_o$ = 500000 m
False east (value assigned to the natural origin)	Y_o = 500000 m	Y_o = 500000 m	$E_o = Y_o$ = 500000 m
Width of zones	6° (24°-30°)	6° (24°-30°)	-
Datum	*Pulkovo - 42*	*WGS-84*	*Pulkovo - 42*
Ellipsoid	*KA-40*	*WGS-84*	*KA-40*
Parameters of the reference ellipsoid	a = 6378245 m f = 1:298.3	a = 6378137 m f=1:298.257223563	a = 6378245 m f = 1:298.3
CRS	*S42-TM35*	*WGS84-TM35*	*S42-ST70*

Within the cross-border projects of the NE region of Romania, the establishment of the map projection for the representation of geospatial data must also take into account the values of the relative linear deformations for the mapped area (Chirilă, 2009). Therefore, for a pilot area established in the Ungheni region, the values of the relative linear deformation for a central point on the studied area are presented, both on the part of Romania and on the part of Republic of Moldova (Table 2).

Table 2
Relative Linear Deformations in the Ungheni Area - Romania / Republic of Moldova

Geographical coordinates φ (° ' ''), λ (° ' '')	*Gauss-Krüger projection*	*UTM projection*	*Stereo -70 projection*
(47°12'00", 27°47'00") (47°12'15", 27°47'45")	+4.3 cm / km +4.5 cm / km	-35.5 cm / km -35.7 cm / km	+13.9 cm / km +14.2 cm / km

In the context of the European recommendations for cartographic representations at scales larger than 1: 500,000 the UTM projection is associated with the ETRS89 datum and the GRS80 ellipsoid (ETRS-TM35 for the NE region of Romania). Using the same European datum for conformal mapping at scales smaller than or equal to 1: 500,000 is indicated the Lambert conformal conic projection with two standard parallels (ETRS-LCC). For pan-European mapping intended for statistical analysis at any scale, Lambert azimuthal equal area projection (ETRS-LAEA) is recommended (Annoni *et al.*, 2003).

3. Coordinate Reference Systems for Vertical Positioning

Vertical geodetic networks have been designed and executed separately from horizontal networks, based on different principles and methods, through which heights are generally referred to the gravity field and less to the ellipsoidal system used in horizontal positioning (Torge, 2001). The methods of surveying are mainly based on geometric leveling measurements. The first order network is developed in the form of polygons that ensure the uniform coverage of the entire national territory (Fig. 3*a*).

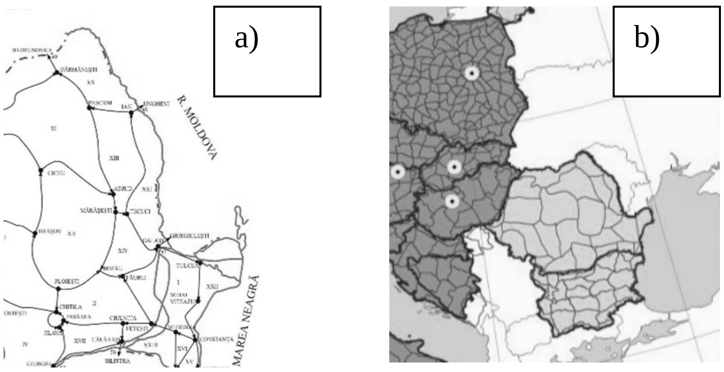

Fig. 3 – The first order leveling network in the NE region of Romania (*a*) and the leveling polygons used in Romania for EVRF2007 as realization of EVRS (*b*) (Ghițău, 1983; Dragomir *et al.*, 2011).

Initially, the national leveling network (1961-1971) was developed in the Kronstadt vertical datum, with reference to zero Baltic Sea, which uses a height system based on Molodenski's concept of normal heights. The leveling relative to zero level of Baltic Sea datum was introduced in the country through the Giurgiulești and Ungheni leveling landmarks. The leveling landmarks connecting to the national network were located in the localities of Galaţi and Iaşi (Fig. 3*a*).

Then, the Topographic Military Directorate (DTM) established the mean level of the Black Sea at the epoch 1975, by processing the data recorded between 1933-1975 at the Constanța tide gauge (Anton *et al*., 2016). The official reference system is called the Black Sea "zero Constanța 1975" and has the European code RO_CONST / NH. The epoch of the datum realization is 1989 and it has kept the same system of normal heights as the previous datum.

Romania participates since 2007 in the European Vertical Reference System (EVRS) by integrating in the latest solution EVRF2007, contributing to this by extending the data set to 48 common points with ETRS89 ellipsoidal heights and Black Sea - 1975 normal heights (Fig. 3*b*).

EVRF2007 is considered the vertical spatial reference for pan-European geo-information. The vertical datum is an equipotential surface of constant gravity field potential (W_o), which coincides with the level surface of the Amsterdam Ordnance Datum (NAP). The components on height are the differences of potential relative to the fundamental landmark and are expressed by geopotential numbers. By specifying the normal gravity field (GRS80 level ellipsoid and the ETRS89 coordinate reference system), heights can also be expressed in the normal height system (Dragomir *et al*., 2011). For the territory of Romania, the description of the transformation is presented, which ensures a sub-centimeter precision (Table 3).

Table 3

Transformation Parameters RO_CONST – EVRF2007

CRS identifier	Operation method	Applied formula	Parameter values
EVRF2007_AMST / NH	3 parameter height transformation	$H_{(RO\_CONST)} = H_{(EVRF2007)} + a1 + a2 \cdot Mo \cdot (\varphi - \varphi_o) + a3 \cdot No \cdot (\lambda - \lambda_o) \cdot \cos(\varphi)$	a1 = +0.062 m a2 = -0.005" a3 = +0.008" φ_o = 46°01' N λ_o = 24°49' E

4. Coordinate Reference Systems for Three-Dimensional Positioning

With the new technologies of data integration through satellite measurements, a unification of the two components of the spatial position of a point has been reached, the horizontal and vertical determinations being included in a spatial geodetic datum, defined in relation to a global coordinate system. This datum is the basis for the design of spatial geodetic networks in which the three-dimensional coordinates (X, Y, Z) of the network points are determined simultaneously and with homogeneous precision using GNSS technology.

In Romania, after 1990, the first spatial geodetic network was created, having "Dealul Piscului" landmark as origin, together with 6 other A-order points, from which "Sârca" point (Iaşi county) belongs to the NE region of

Romania. The coordinates of the points were obtained in the reference system ITRF92, epoch 1994.7, after which they were transformed into the European reference system ETRF89 - EUREF.

Since 2008, through ANCPI, the ROMPOS (Romanian Positioning Service) is operational, which is based on the distribution in the territory of permanent reference stations with complex use (navigation, geodetic positioning, weather data), interconnected and located at an average distance of 70 kilometers between them (ancpi.ro). Data provided for post-processing (< 2 cm) and real-time (≈ 3 cm) positioning are available in both the European reference system (ETRS89) and the national system (stereographic - 1970).

The current National Geodetic Network comprises:

- The class A (primary) GNSS network, consisting of 75 permanent GNSS stations (Fig. 4*a*) determined with a precision of up to ± 1 cm;

- the class B (secondary) GNSS network, having 303 points, 7 points each on the territory of a county, of which at least two points belong to the classical triangulation network with a spatial determination precision of less than ± 2 cm (Fig. 4*b*);

- the class C (tertiary) GNSS network, with a number of 1156 points, with an average of approximately 100 points at the level of a county (1 point / 50 km^2) with a spatial determination tolerance of ± 3 cm (Fig. 4*c*).

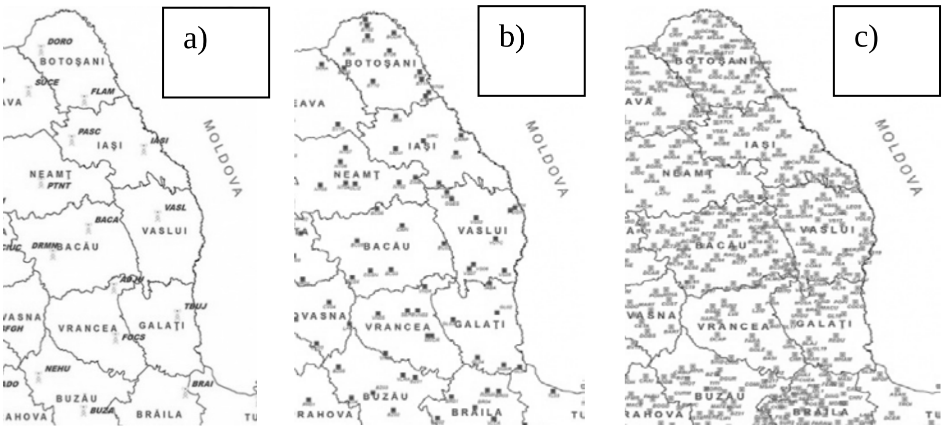

Fig. 4 – National Geodetic Network (GNSS) of CLASS A (*a*), CLASS B (*b*) and CLASS C (*c*) - detail from the NE region of Romania (@ *CNC / ANCPI*).

5. Coordinate Conversions and Transformations Between Spatial Reference Systems for the NE Region of Romania

Coordinate conversions and transformations are conceptually defined and classified according to the European standard for geographic information (ISO 19111), as mathematical operations that change the expression of the spatial position of a point relative to the initial datum (conversion) or another final datum (transformation). Thus, for the official datums in Romania, a scheme of the possibilities of coordinate conversions and transformations between different coordinate reference systems (CRS) specific to the NE region of Romania can be synthesized (Fig. 5).

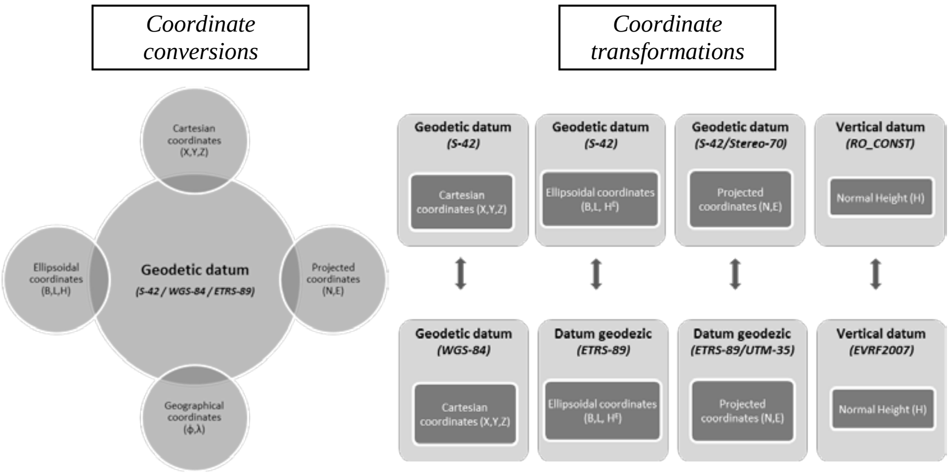

Fig. 5 – Possibilities for coordinate conversions and transformations between different coordinate reference systems (CRS).

As part of the surveying activities, coordinate conversions and transformations have been included in a standardized guide developed by the "European Petroleum Survey Group" (EPSG), which became "OGP (Oil and Gas Producers) Surveying and Positioning Committee" in 2005 (OGP, 2014).

Thus, for Romania a number of 5 conversions can be selected (Fig. 6), respectively 44 coordinate transformations, of which only the most common are highlighted (Table 4) (epsg.org/home.html).

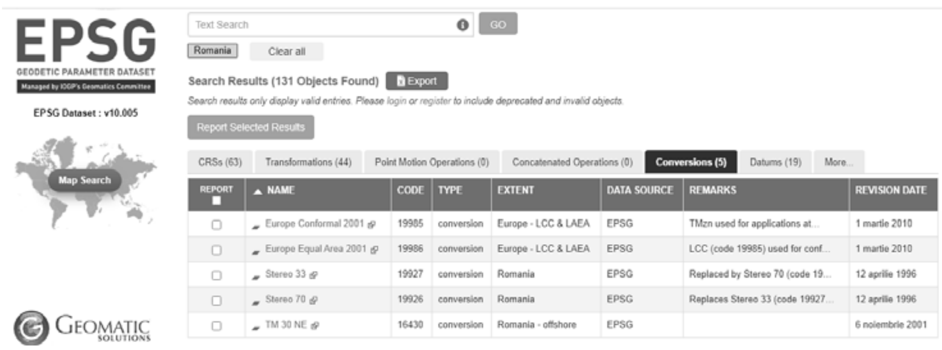

Fig. 6 – Search results of coordinate conversions for Romania in the EPSG work guide.

When choosing a coordinate transformation model, a number of criteria must be taken into account, of which the fundamental is the number of dimensions of the coordinate system (3D, 2D or 1D) and for each case it is to ensure the precision of coordinate transformation.

Table 4
Selected Results of Coordinate Transformations for Romania in the EPSG Work Guide

Transformation Name	Code	Extent	Remarks	Revision date
Constanta height to EVRF2000 height (1)	5205	Romania - onshore	Determined at 46 points …	March 14, 2020
Constanta height to EVRF2007 height (1)	5206	Romania - onshore	Determined at 48 points. …	March 14, 2020
ETRS89 to WGS 84 (1)	1149	Europe - ETRF by country	ETRS89 and WGS 84 …	March 14, 2020
Pulkovo 1942(58) to ETRS89 (3)	15993	Romania	Withdrawn and replaced by S-42…	March 14, 2020
Pulkovo 1942(58) to ETRS89 (4)	15994	Romania	Replaces S-42 to ETRS89 …	March 14, 2020
Pulkovo 1942(58) to WGS 84 (18)	15496	Romania		March 14, 2020
Pulkovo 1942(58) to WGS 84 (19)	15995	Romania	Parameter values taken from …	March 14, 2020
Pulkovo 1942(58) to WGS 84 (9)	15497	Romania	Derived at 4 stations…	March 14, 2020

Some of the coordinate transformations specific to the national territory are already implemented and formalized in the TransDatRO application (currently on version 4.06) developed by ANCPI (Fig. 7).

Fig. 7 – Coordinate transformations for Romania, in the TransDatRo (v4.06) application.

The most important achievement is the horizontal coordinate transformation from the ETRS89 European system into the S42 local datum with the Stereo-70 map projection. Coordinate transformations are performed using a data distortion model leading to a standard deviation of the transformed coordinates around ± 10-15 cm (Avramiuc *et al.*, 2009). In the case of height transformations, the central agency has an ongoing project to determine a gravimetric quasigeoid for the area of Romania whose average precision of transformation of new points is estimated at around ± 10-12 cm. In the NE region of Romania, only the geometric quasigeoid is used so far, whose accuracy can vary between ± 16-50 cm (rompos.ro). Compared to this situation, a local modeling of the quasigeoid can be used and for the NE region of Romania a 3D model of the quasigeoid in the Prut-Bârlad river basin area was created in a project of the Romanian Waters company (Fig. 8).

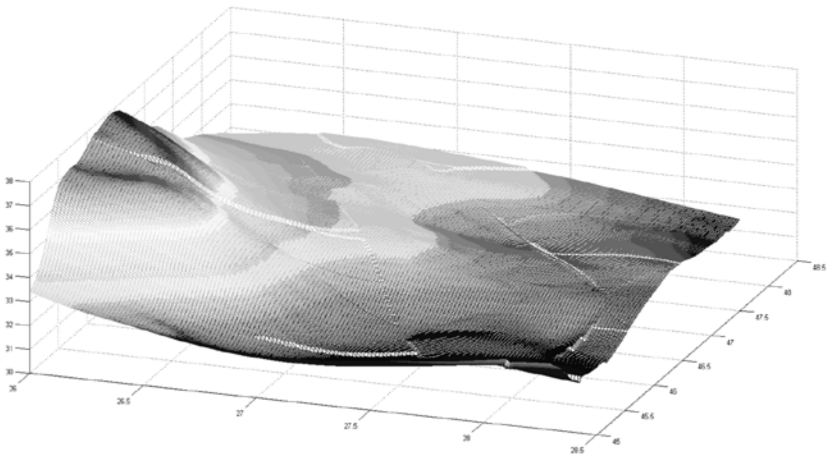

Fig. 8 – 3D model of the quasigeoid in the area of the Prut-Bârlad river basin (Dumitru *et al*., 2013).

The mean difference obtained for the control points between the model data and those in the measurements was ± 3 cm.

6. Cartographic Products in the Datums Used at National Level

Maps and plans made in analog format are a valuable potential, which can be used as a data source in creating digital map support. At the national level, the main institutions that contributed to the creation of the cartographic fund are the “Defense Geospatial Information Agency” (AIGA) and the “National Agency for Cadaster and Land Registration” (ANCPI), through the “National Center of Cartography Romania” (CNC). Among the significant achievements in the cartographic field of these institutions are:

a) *National cartographic products in the WGS-84 datum* (@ AIGA-geomil.ro):

- Basic topographic map of Romania at a scale of 1:25,000 in UTM projection (UTM34; UTM35);
- Basic topographic map of Romania at a scale of 1:50,000 in UTM projection (UTM34; UTM35);
- Ortho-rectified aerial images with 50 cm resolution edition I (2010-2013) in UTM projection - (UTM34; UTM35).

b) *National cartographic products in the S-42 datum* (@ AIGA-geomil.ro):

- Basic topographic map of Romania at a scale of 1:25,000 in the Gauss-Krüger projection and with the reference plan of the Kronstadt - Baltic Sea heights;
- Basic topographic map of Romania at a scale of 1:50,000 obtained by generalizing the content of the topographic map at a scale of 1:25,000;
- Basic topographic map of Romania at a scale of 1:25,000 in the Stereo-70 projection;
- Basic topographic map of Romania at a scale of 1:50,000 in the Stereo-70 projection;
- Basic topographic plans of urban areas at the scales 1:5,000 and 1:10,000 in analog, raster or vector format;
- Vector Map of Romania made for level 1 and level 2 at a scale of 1:50,000;
- Ortho-rectified aerial images with 50 cm resolution, first edition (2010-2013) in Stereo-70 projection;
- Artillery master plans in Stereo-70 projection;
- The numerical model of the terrain with the resolution of 25 m and 75 m at national level – Stereo-70 projection, reference to the Black Sea;
- Romania's border with the Republic of Moldova (Stereo-70 projection) – digitization of intermediate points on the topographic planes at a scale of 1:10,000 and 1:5,000. The relative accuracy of determining the coordinates of the border points is 2 m over the whole segment.

c) *National cartographic products in the S-42 datum* (@ CNC- cngcft.ro):

- Updated basic topographic map;
- Updated cartographic products derived from the basic topographic map of Romania:
  - execution of the basic cadastral map of Romania at a scale of 1:50,000 and partially at a scale of 1:25,000;
  - updating the basic cadastral map at a scale of 1:50,000 using remote sensing methods.
- Folding maps at a scale of 1:50,000 in Stereo-70 projection, reference plan Black Sea 1975 (1990 edition);

- Basic topographic plan at the scales 1:2,000, 1:5,000 and 1:10,000 by photogrammetric methods and the cadastral plan derived from it;
- Romania's topographic reference plan in digital format corresponding to the scale 1:5,000, by processing the orthoimages mosaic (TOPRO5);
- Generalization of the TopRO5 model;
- Cartographic products made in digital format:
- Topographic plan at a scale of 1: 5,000 for natural hazard areas on the entire territory of Romania;
- Realization and updating in digital format of the border limits of the territorial administrative units in Romania.
- Realization of the digital model of the terrain based on the representation of the relief through the contour lines extracted from the basic topographic map at a scale of 1:50,000.

7. Conclusions

The framework for defining spatial reference systems for cross-border projects in the NE region of Romania requires the correlation of coordinate reference systems between the two neighboring states, Romania and the Republic of Moldova. Thus, on extensive areas for monitoring hazardous phenomena, a compound coordinate reference system will be chosen, consisting of a CRS1 for horizontal positioning and a CRS2 for vertical positioning. In the definition of CRS1, the main importance is the geodetic datum and secondary the map projection. Actually, the common datums are ETRS89 and Pulkovo-42 (S-42) while the map projection will be adapted by mutual agreement between the parties. For CRS 2, the height system will be the normal heights, with the possibility of the option for the RO_CONST, Baltic - 1977 or EVRS2007 datum (Fig. 9).

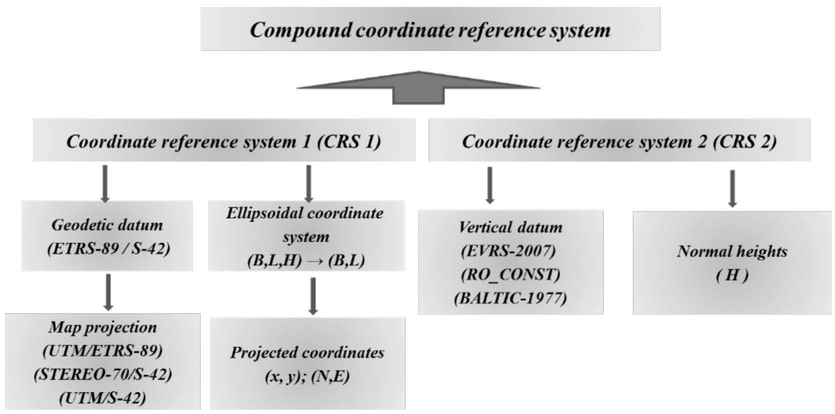

Fig. 9 – Compound coordinate reference system for the NE region of Romania.

In the case of small study areas for monitoring engineering objectives, such as hydrotechnical constructions, bridges, landslides, etc., the compound coordinate reference system will consist of a CRS1 for horizontal positioning (engineering datum and projected coordinate system) and CRS 2 for vertical positioning (vertical or engineering datum and normal or orthometric height system).

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PREZENTARE GENERALĂ A SISTEMELOR DE REFERINȚĂ SPAȚIALE PENTRU MANAGEMENTUL RISCULUI DE HAZARD ÎN REGIUNEA DE NE A ROMÂNIEI

(Rezumat)

Lucrarea își propune ca obiectiv prezentarea cadrului general al referinței spațiale pentru geoinformația din regiunea de NE a României, în scopul unei abordări unitare a proiectelor comune transfrontaliere cu Republica Moldova în domeniul managementului riscurilor la hazard. Datorită multitudinii surselor de date spațiale care intervin în astfel de proiecte și a prelucrării măsurătorilor geodezice pe diferite suprafețe de referință, este necesară o prezentare distinctă a sistemelor de referință și coordonate pentru poziționarea planimetrică, altimetrică și tridimensională. În operarea cu aceste sisteme de referință și coordonate apare în mod implicit necesitatea conversiilor și transformărilor de coordonate, care trebuie efectuate în limitele unei precizii acceptabile, conform cerințelor proiectului. De aceea, în cadrul lucrării se conturează un ghid practic în lucrul cu datele geospațiale asociate datumurilor şi proiecţiilor cartografice pentru această regiune. În ultima parte a lucrării, se prezintă fondul cartografic existent la nivel național corespunzător datumurilor oficializate în România în ultimele decenii și în final, se propune cadrul de definire al sistemelor de referință spațiale pentru proiectele de tip transfrontalier.