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PhD THESIS

Hydrological risk assessment for Danube Fluvial Delta

abstract

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SUMMARY

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Keywords: Danube River Delta, flood hazard, vulnerability to flooding, flood risk, risk assessment

Introductory Elements

This paper is divided into fifteen chapters, each chapter with its purpose of scientific logic of the thesis. The first chapter is about the justification of this thesis , namely bringing argument of its existence followed by defining and detailing the terms that will be used later in the thesis.

Thus this paper is developed on the grounds of the need for analysis or assessment of risk hydrological river Danube Delta . The need arises from the fact that in the last 20 years there has been an increased frequency of extreme meteorological and hydrological phenomena due to climate change caused by humans. As an example may be mentioned the special hydrological events lately. A first notable hydrological event was low water levels tied to the River Danube in 2003, when at the Ceatal Izmail was recorded value of 0.737 m above the reference level of the Black Sea - Sulina (rMNS) . In 2006, on 26-27 April, at Ceatal Izmail, there was a level of 5.4 m above rMNS and discharge of 16440 m3/s (April 26 there was a level of 4.93 m rMNS at Tulcea). A third important hydrological event refers to the high water levels of the Danube in 2010: at Isaccea on July 6, was recorded a level of 6 m above rMNSm and 4.95 m rMNS at Tulcea, 2 cm higher than in 2006.

Danube Fluvial Delta is part of the Delta which is located in the South -East of Romania or in the North -Western part of the Black Sea region in the mobile crust (PreDobrogean Depression). Its limits are : 44° 46' 00" N latitude (Periteaşca), 45° 30 '00" N latitude (south of Lake Sasik), 28° 40' 24 " E longitude (Ceatalul Izmail), 29° 40' 50" E longitude (east of the Chilia’s secondary delta). Delta limit itself can be extended to Cape Midia, including Razim - Sinoe (includes Lake Razim Zmeica, Sinoe and Goloviţa) (Romanescu , 1999) (Fig. 1)

Fig . 1 Geographical location of the Danube Delta in Romania

History of research can be divided into two periods : ancient , modern and contemporary (Romanescu , 1995a) . Old period runs from the first observations made by Herodotus and 1856, when in fact studies are undertaken purely scientific detail . It is virtually non - scientific period , based only on reported facts surface without them find the cause .

The second is the modern and contemporary period , which began in 1856 , when the European Danube Commission was formed and began development studies for channeling Sulina branch (Romanescu , 1995a).

Since the main theme of this paper concerns the hydrological risk in general, and the floods in particular can remember and authors who have published outstanding work in the field.

Internationally there is a concern in all areas of hydrological risk , especially regarding the flood : Acreman , 2000; Affeltranger , Lictorout , 2006, Alho et al. , 2010; Andzanc et al. , 2010, Call et al., 2004, 2009; Arduino et al. 2005, Assani et al., 2006; Barredo, 2007 etc.

Most publications aimed at risk hydrological phenomena and measures can be taken to counter them . From this point of view hydrology Romanian school was involved fervent in recent years, especially by developing studies based GIS applications.

Descriptive Elements

Delta as a form of dynamic relief, at the mouth of the most international European river knows emphasized the transformation process. Progradation is active at the mouth of the three arms (Chilia, Sulina, St. Gheorghe) and erosion models beside the brook attributable coast and the mouth portion.

Delta has an average height of 0.52 m, resulting from the sum of all values and mediating elevation (on the steps hypsometric) of all subunits, generalized delta entire space. Measurements were carried out on the map I. Vidrascu showed an average altitude of 0.31 m (Gâştescu, Driga, 2006, 2008).

Recent measurements (2011 unpublished data) reveals that the maximum depth encountered Tulcea arm -39 m depth is high due to the strong tidal Tulcea arm forming a vortex when the bank meets concave meander beside Delta Hotel.

Closely related to relief is Delta climate described in Chapter VI . Delta is part of the arid continental climate type Danube (river obvious influences), characterized by high thermal amplitudes , the active wind regime and low rainfall . Dn upstream to downstream is recorded significant variations in climate Danube.

In terms of hydrological river branches are major thoroughfares that provide space deltaic river liquid and solid flow . Before branching river at Ceatal Izmail (Chilia) , annual average flow of the Danube is 6515 m3/s (period 1921-2000). Arm Chilia (120 km length from Ceatal Izmail (Chiliei)), until 1890 was characterized by a tendency to increase the flow, if we take into consideration the most important aspect that is leaking (Gâştescu, Driga, 2008). Considering the period 1921-2000 can be seen in Figure 2 tend liquid flows on each arm separately.

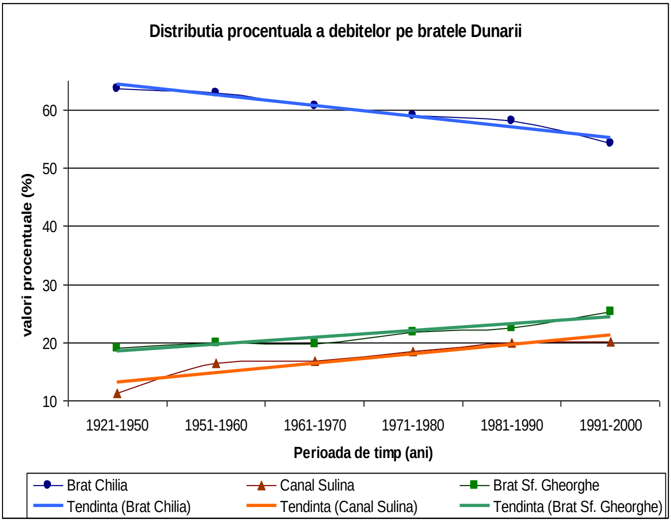


Fig.2 Distribution of discharge and the tendency on the river branches (processing after Bondar, 2004; Gâştescu, Driga, 2008)

In the same chapter there are presented information on the groundwater (deep aquifers and groundwater) and also inundability Delta.

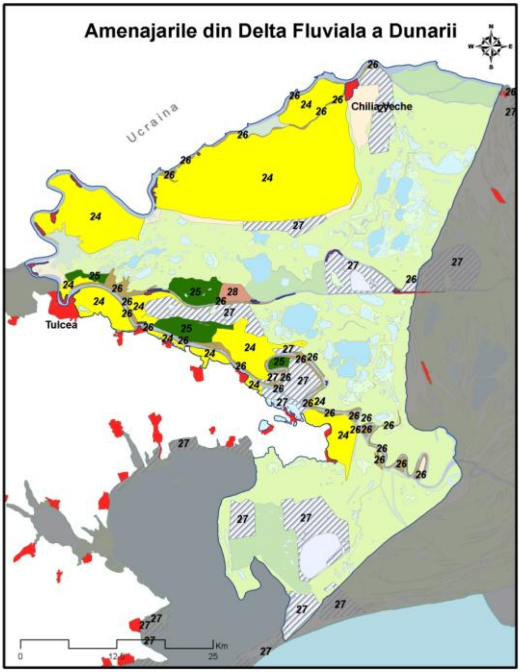
Vegetation and fauna of the Danube Delta is characterized by a particularly high diversity of European and Asian elements is characteristic of the Danube Delta Biosphere Reserve , both in terms of postglacial refuges and the current geographical distribution of species.

As a support for animal species and plants soils are throughout the Danube Delta Biosphere Reserve. In order to develop the Danube Delta pedological research was necessary to extend the concept of ground and underwater lands by creating limnosol term (Munteanu, 1984). It includes lake and lagoon sediments, the formation of which, in addition to mineral suspensions, an important role of organic matter resulting from rotting vegetation and floating aquatic fauna including debris. At the same time has been created new subtypes gleyic and organic soils (gley soils submerged organic soils natant etc.) and introduced many new diagnoses characters (physical maturation index, character and sulphate sulfuric acid, etc.).

To discuss the risk should be considered anthropogenic component in deltaic system . Thus characterization of anthropogenic component targeted settlements . From their analysis showed that there is a close correlation between the location of settlements in the delta area and their characteristics morphostructural. Classification according to two criteria corresponding delta levees. Fluvial prints linear form settlements and hearth appreciable length (13 km to Crisan). Narrow strip separating surfaces River delta marsh itself, only less likely to flood , is occupied by buildings . Under these conditions the dams become a compulsory attendance as some unforeseen navigation gait sometimes endanger security habitat (vessel failure " Rostock " , when they were destroyed several houses in the town Partizani) (Dobraca et al., 2008).

Anthropogenic component in addition to presenting population is represented by agriculture and forest meaning the area and type of use of the facilities of all types (

agricultural, forestry, etc.). Arrangements made in the Danube Delta were created around the three arms . In this case the transport is essential for the entrances and exits of facilities . The highest density and the highest number of facilities are along the jib Saint George , along Chilia and along the Sulina channel (Fig. 3).



24.Agricultural polder, 25.Forestry polder; 26.Planted Poplar on river banks ; 27.Fishpounds ; 28.Complex polders

Fig.3 The fitting of the territory of the Danube river delta (processing after Gâştescu et al. , 1996)

Flood Hazard Research

In chapter flood hazard research began with general then explaining the numerical model of Land developments gaining major importance in that it led to the creation of hazard map for Delta River . This model for the river delta of the Danube was developed using LIDAR data processing (Light Detection and Ranging) LIDAR is a powerful method to acquire data sets with a collection system that provides 3D information for an area of interest or an area involved in the project . They are useful for mapping land surface, vegetation corridors and building 3D maps (Young, 2011) . From the entire DDBR MNT was extracted MNT for the river delta area . This could be executed by the process of Clip (cutting) of the tools of the program of work environment GIS , ArcView 3.x (Fig. 4).

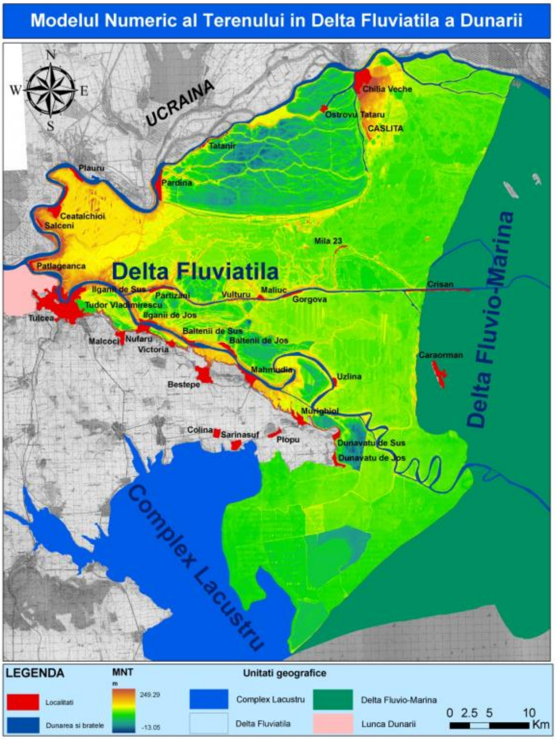


Fig . 4 The number of the Danube river delta Land

After developing MNT 's get past the drawing fluid component hazard levels using data from hydrological gauging stations in the river delta (Ceatal Izmail, Padina, ChiliaVeche, Periprava, Tulcea Port, St. Gheorghe, Gorgova, Crisan, Mile 23, Mahmudia and Upper Dunavatu to support hydrologic data points were used four levels :Saint George and Cerneşti (between Chile Old and Periprava) Jurilovca and Portiţei. stations in Razim - Sinoe can provide data that correlate with the arm of St. George. reading levels Four points are placed within the river delta . Paragraph Mile 23 has a central position. majority of stations are located on the main arms of the Danube. relatively uniform distribution of the points of observation makes the analysis to be truthful . were selected data from two extreme hydrological events occurring in river delta: the very low levels in 2003, very high levels in 2006. for a better understanding of flood levels correlated graphs are drawn from a number of stations hydrometer or observation points . a first set of correlations targeted entry point of water in river delta (Ceatal Izmail) and other stations (Fig. 5, 6 , 7, 8).

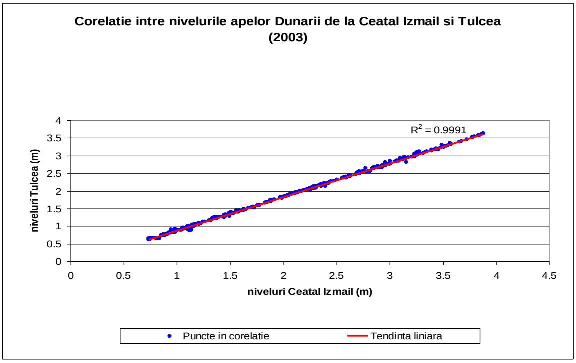


Fig. 5 Correlation plot values Ceatal levels at gauging stations and Tulcea Izmail in 2003

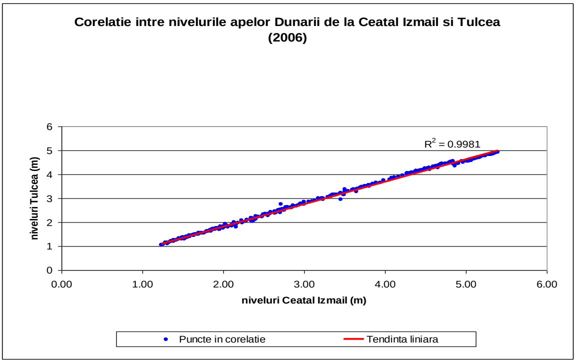


Fig. 6 Correlation plot values Ceatal levels at gauging stations and Tulcea Izmail in 2006

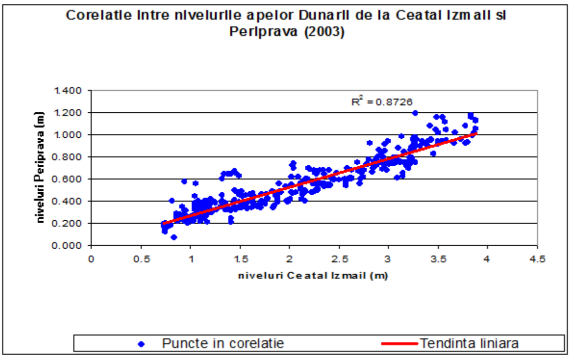


Fig. 7 graph correlation values Ceatal levels at gauging stations and Periprava Izmail in 2003

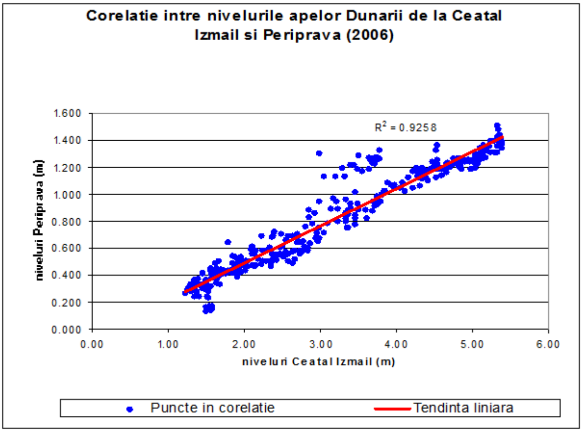


Fig.8 Graph correlation values Ceatal levels at gauging stations and Periprava Izmail in 2006

Correlations were calculated between all hydrometric stations where they were registered coeficientrului correlation r2 values above 0.8 which means a high correlation between the data (Fig. 9, 10 and 11).

Levels of delta river gauging stations correlate very well in both cases: low waters and high waters. There is a very small decrease in correlation from west to east. Is only weak correlation with river-sea delta, where water is routed to the central depressions. At low levels in 2003) the correlation coefficient becomes significantly at lower values as the correlation station is located downstream (Fig. 11). In this case a large part of the water of the arm is directed to another route and not entirely on the downstream reaches. A possible alternative is the channel Mila 35. For 2006 there is a station right inflection Pardina. Can be attributed to low water velocity following two routes: the arm itself; channel Mila 35. Value increases as the submission to downstream, with figures higher than in 2003. The increase is due to the higher speed water to the higher level.

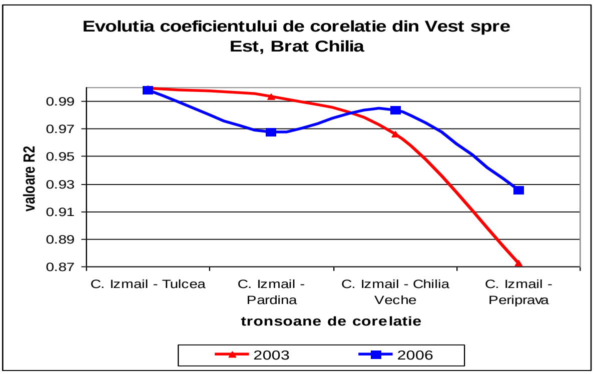


Fig. 9 The evolution of the correlation coefficient west to east arm of Chilia (2003 and 2006)

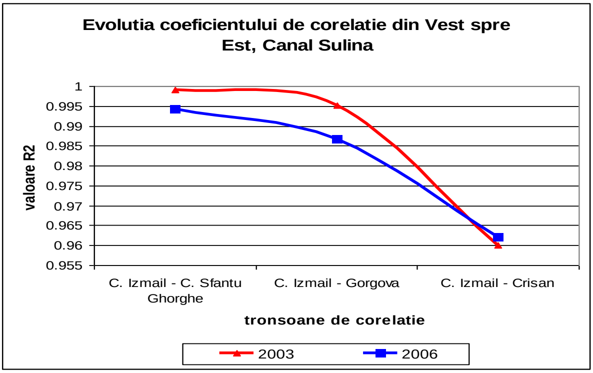


Fig. 10 Evolution of the correlation coefficient from west to east on Sulina Channel (2003 and 2006)

Correlation coefficient decreases downstream from higher values in 2003 to lower values than in 2006 (Fig. 10). At low water levels do not "invade" the inner areas. At high water flooded some inland areas. Correlations for Sf Gheorghe demonstrates that the waters are only slightly lower coefficients and correlation coefficients in shallow water have slightly higher values (Fig. 11).

Analysis of correlation values Danube water levels on the three arms (Chile, Sulina, St. George) provides data that allows the use levels in later interpolations. The values of correlation coefficients between data levels were mostly above 0.9. The exception is Periprava station with $R2 = 0.8726$, for 2003.

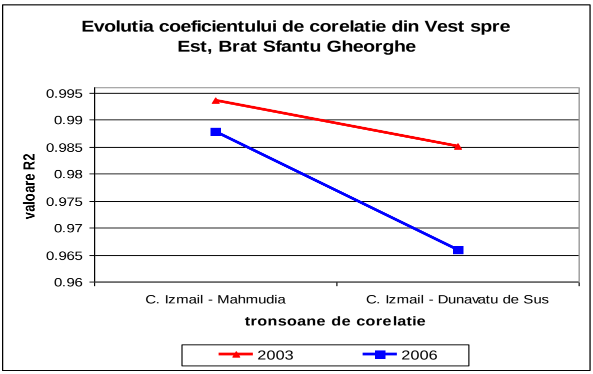


Fig. 11 Evolution of the correlation coefficient from west to east St. George Arm (2003 and 2006)

With level data that confirm the correlation between the different gauging stations for the two extreme hydrological events (very low levels in 2003 and floods in 2006) have been developed for the entire area maps of the studied levels (Fig. 12) using spline interpolation method. This method was used because the estimated values (interpolated) using a mathematical function that makes a minimum curvature between interpolated points. It is suitable for modeling water surface.

The results of the interpolation values at the minimum levels (Fig. 12) and the maximum level are files square cell grid, wherein the side is five meters above the ground. Since the area studied is large scale is small, it is considered that side of the unit cell of five feet from the ground is sufficient for hazard analysis.

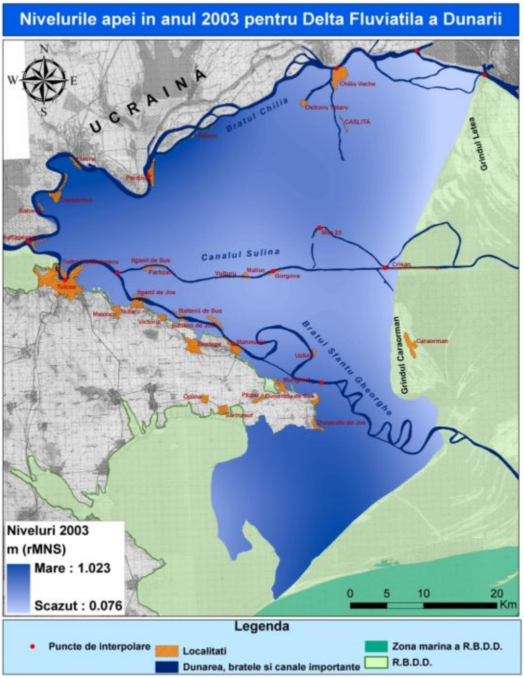


Fig. 12 Map of minimum water levels of the Danube river delta in 2003 (m rMNS)

Low levels of water in the Danube Delta and Interpol for 2003 has several levels (Fig. 12) on the right Chilia Arm localities Ceatalchioi, Plauru, Pardina, in the south of the river delta. The lowest values of the level of 2003 are on the right side of Sulina Channel localities: Vulturu, Maliuc and Gorgova. Low levels of water levels were recorded at transition to delta water transport, on the entire east side.

Map of maximum water levels of the Danube river delta reveals a maximum in the west, settlements on the right Pătlăgeanca, Sălceni, Ceatalchioi, Plauru, Tulcea and Tudor Vladimirescu. From west to east, almost concentric, there is a decrease in water levels. This decrease is due to the fact that the water entering from the west, in one way (the Danube) begins to split in two arteries: Chilia and Tulcea. In this case, less tense "pressure" and lower levels. Lower levels as delta surface area increases and the water is deffussing. The difference between the two extreme situations gives the maximum amplitude value.

Highest amplitude occurs in the western part of the river delta, with extension Tulcea arm and St. George arm. The maximum value is 4.662 m and was calculated near Ceatalul Izmail. The lowest value (minimum amplitude) was calculated for the north-eastern river delta in the southwest sector (Razim - Sinoe). Knowing which is the maximum amplitude in the study area could be created hidrogrades. Figure 13 illustrates the map of water depth at hidrogradul 10.

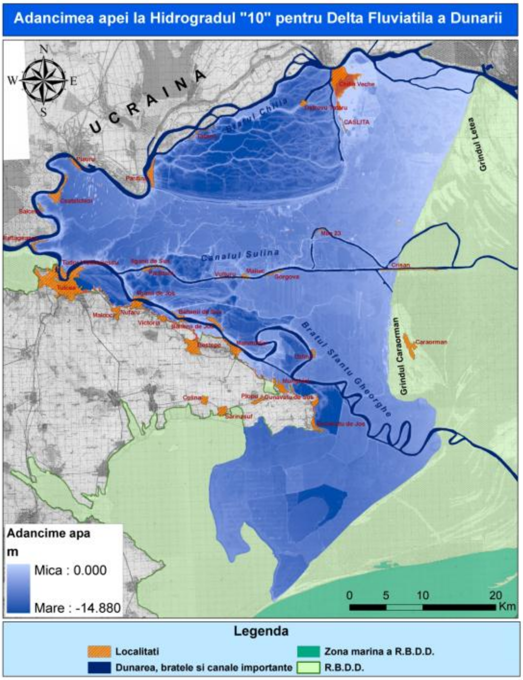


Fig.13 Water depth map hidrogradul 15 "10" for the Danube river delta

For example Agricultural Precinct Pardina was taken to observe what happens to water at different hidrogrades. Pardina agricultural precinct is intended for crops. There labour works on polder system. The proposed scenario for modeling assumes dam failure and flood waters invading land. It was determined the area of agricultural enclosure, surrounded by protective dike. For agricultural polder Pardina the hidrogrades have a vertical layout. Horizontal expansion is limited because the unit is depression. For each hidrograde it has been calculated the volume of water stored (Table 1).

Tabel 1 Numerical data regarding flooding situation at different hidtrogrades for Pardina Agriculture Polder for different hidrogrades

Hydrograd	Surface 2D (m^2)	Surface 3D (m^2)	Water volume (m^3)	Î medium (m)
H "0" (nivel 2003)	240255600	240352107.9	231970308.4	0.135
H "3"	272044525	272217181.7	620970807.8	0.362
H "5"	273114575	273301261.8	768691060.8	0.449
H "8"	273211275	273400002.6	810423879.8	0.473
H "10" (level 2006)	273459425	273654060.5	958271749.4	0.559

As calculated for the entire fluvial delta data are shown in Table 2.

Table 2 Numerical data on the situation of the Danube river delta flooding for different hydrograde

Hyidrograds	Surface 2D (m^2)	Surface 3D (m^2)	Water volume (m^3)
H "0" (nivel minim 2003)	921678000	921867378.8	537987176.6
H "3"	1996892825	1997500752.3	2903802197.3
H "5"	2063668025	2064458805.2	4025172040.2
H "8"	2081198400	2082087059.0	4538008780.3
H "10" (maxim level 2006)	2112239875	2113277467.7	5722396383.8

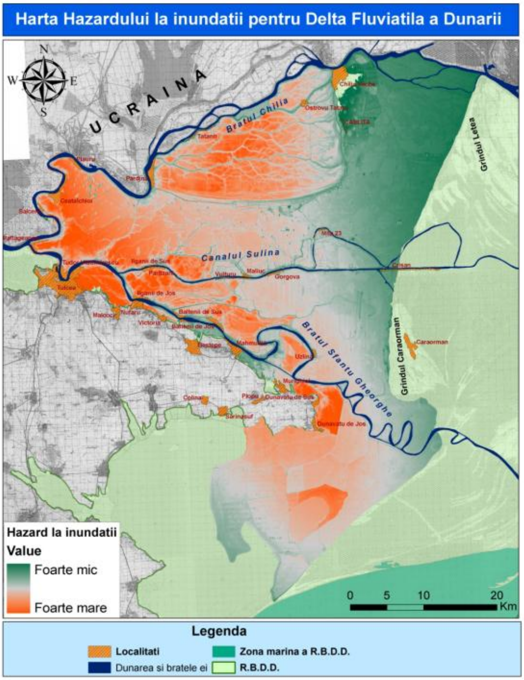


Fig. 14 Flood hazard map for the Fluvial Delta of the Danube

Flood hazard map (Fig. 14) was made on the basis of amplitude levels and water depth at maximum levels in 2006 (Fig. 13). Flood hazard in the western sector of the fluvial delta is larger and decreases eastward. In this case exerts a pressure on the river enters the delta, from Izmail Ceatalul. Once you have entered the Danube arms this pressure gradually decreases (Fig. 14). Flood hazard decreases from the inside of the arms and the Danube delta channels. In this case towards the interior of the delta pressure drop as it is given by the ratio of the force and unit area. With the same method, but with a ground resolution of 1 m2 were made hazard maps of localities. Hazard Were Divided into ten classes values balanced for Several representative localities of the Danube Fluvial Delta.

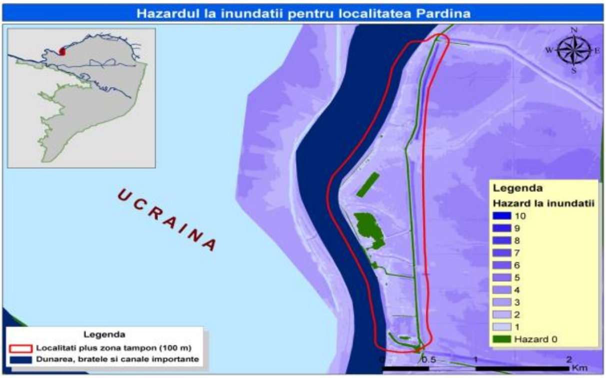


Fig. 15 Map of flooding hazard for Pardina locality

In the locality there are two platforms that are Padina outside chance calculated with hazard 0 (Fig. 15). They raised platform which provides central part of the village. The hazard category 0 and dike defense falls behind the village, to inside Padina.

Research vulnerability to floods

Vulnerability research throughout the study area were considered as vulnerable elements of Delta soils, land cover, and ecosystem types. For each set of data discussed previously was created a table were given grades of vulnerability (from 0-5, with 5 being the highest value of vulnerability), for example (Table 3) for the cation type. By combining the three data sets results vulnerability map of the Danube river delta (Fig. 16)

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Table 3 notes the vulnerability to flooding of soil types of the Danube river delta

Soil Class	Type of soil	Vulnerability Class
Protisoluri	Aluviosol	2
	Entiantroposol	2
	Psamosol	2
Cernisoluri	Kastanoziom	4
	Cernoziom	4
Hidrisoluri	Gleisol	1
	Limnosol	1
Salsodisoluri	Solonceac	3
Histisoluri	Histosol	2
No Class	Nisipuri mobile	1
	Ape curgătoare	0
	Lakes without limnosoils	0
	Soluri din localități	5

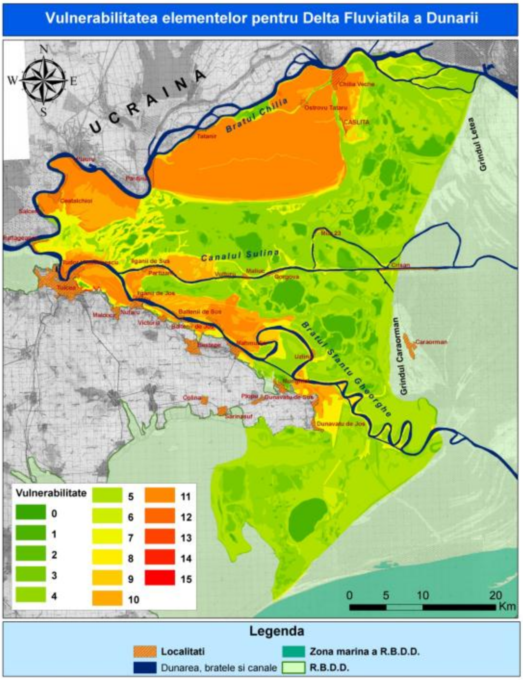

Fig . 16 Vulnerability elements of the Danube river delta

The most vulnerable parts of the Danube fluvial delta are built environments (built or modified by humans). Natural elements have a low vulnerability. Appear "conflict" inherent in man and nature. Water bodies show the lowest vulnerability, while the maximum value is specific to human settlements.

The method used to assess the vulnerability of soils, ecosystems and land cover is in place and in depth analysis of localities. It investigated the vulnerability of human settlements , not taken as a whole, but broken down into its constituent elements. For this purpose we used a data set LPIS (Land Parcel Identification System , that system of parcel identification) . The data set was created under the coordination of Payments and Intervention in Agriculture (APIA). From this data set were extracted only polygons that intersected contour localities, plus another 100 m the buffer . Settlements contour is extracted from the Corine Land Cover data set . Extracting parcels in the LPIS data set within localities was performed using commands intersection. Following this extraction resulting polygons with different uses of the land (maximum 5 being awarded construction and minimal water) .

Following these classifications of parcels within the delta towns on flood vulnerability resulting vulnerability map of localities in the Danube Delta Biosphere Reserve (Fig. 17) .

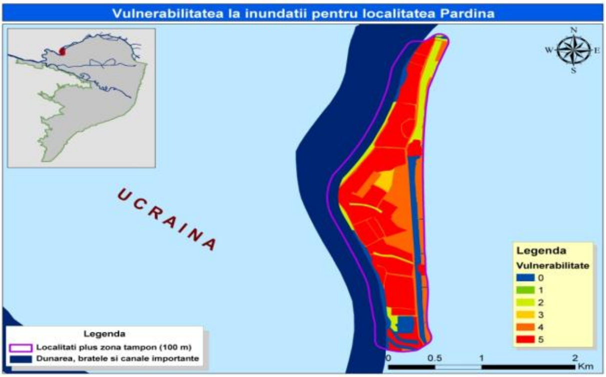

Fig. 17 Flood vulnerability map for the locality of Pardina

All bodies of water present in the river delta are classified as Class 1 flood risk, which demonstrates that they have the lowest risk from flooding . Water bodies not at risk from flooding because it is water itself. In addition to water bodies, all Class 1 flood risk is part and north- east of the delta river: the lacustrine Rosca Buhaiova and the eastern part of lake complex Matiţa - Merhei . The only dry natural territory is a Class 1 is the highest flood risk of land predeltaic Chile. Other areas of dry, insignificant in size, but important as utility , which are Class 1 flood risk are dams in the agricultural area and Sireasa Padina and platforms created for this purpose for some regions (platforms built flood defenses after the floods in 1970) .

Flood Risk Research

According to an empirical relationship is directly proportional hazard risk so was created flood risk map of the Danube river delta (Fig. 18).

The first three classes of flood risk (low risk) totaling an area of 20924.81 ha (over 68 %). The average degree of risk classes (4, 5 , 6) amounts to a total of 8285.01 ha (27.09 %) , while the high risk classes (7, 8, 9 and 10) is 4.49 % (Fig . 19) .

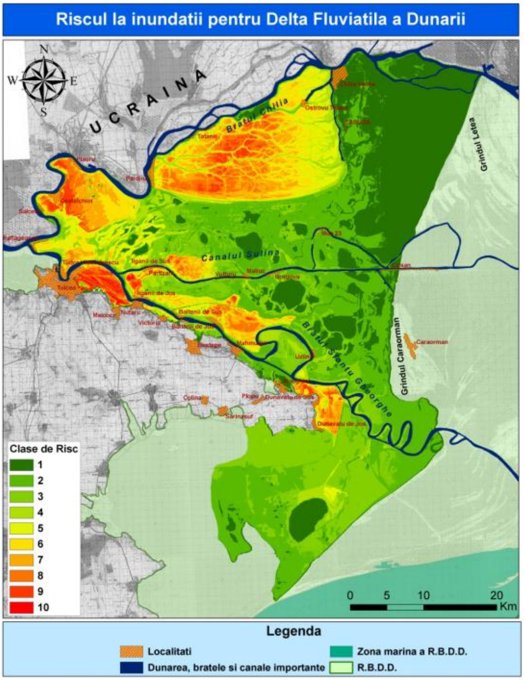

Fig. 18 Flood Risk Map of Danube River Delta

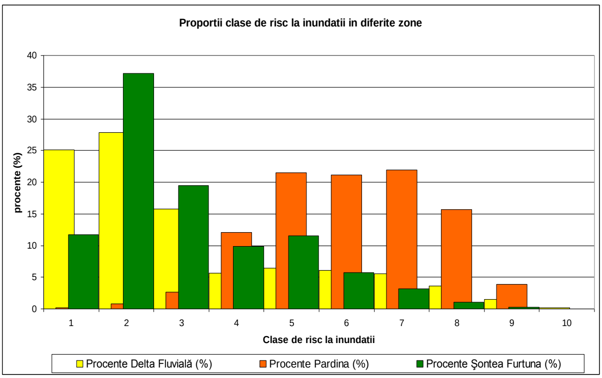

Fig . 19 Proportion classes in river delta flood risk in agricultural development and the lacustrine Padina Şontea - Storm

The distribution of the maximum values is Padina enclosure classes 5 , 6 and 7 . In the lacustrine sont - storm is a maximum surface distribution in classes 2 , 3 and 5. For the entire delta there is a high rate of risk classes 1 , 2 and 3 (Fig. 19) .

For localities in the river delta applied the same methodology, but with other data sets. It should be noted that to build a legend common to all localities was taken place with the largest spread of values of risk . This difference of values was divided into ten classes fair values . First class is very low values , and the last maximum . In areas with very low risk Padina flood (classes 1 and 2) are numerous , they occupy space on the Sand River and the dam (Fig. 20). The two platforms flood defense under category without risk. This category is not taken into account for drawing the graph (Fig. 21) . Padina village area is concentrated in the first four classes of flood risk (approximately 240 ha). The remaining 5.6 ha is occupied by descending from class 5 to class 10 . The town Padina are 3275 m2 under high and very high risk to flooding. Mean flood risk is relatively low (5.3 ha).

Fig. 20 Flood Risk Map for locality Padina

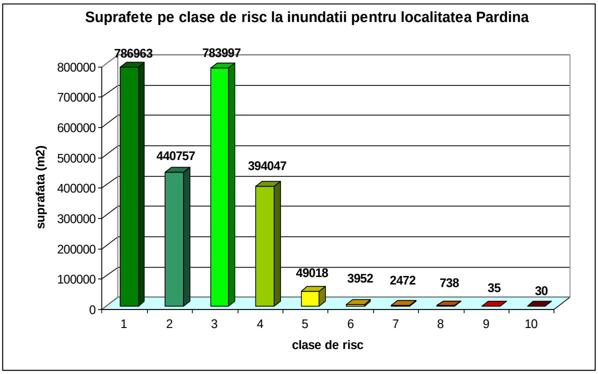

Fig. 21 Areas of flood risk classes for locality Padina

Conclusions

The highest values were recorded in hazard areas west of the river delta , the agricultural area of mixed fisheries , forestry , etc. . that ground level low enough to accumulate considerable water depths .
Vulnerability was determined by combining multiple data sets to have a closer picture of the surrounding reality . By combining data sets on soils Danube Delta ecosystem types and land cover classes resulting vulnerability map of the Danube river delta .
Vulnerability to localities in river delta , is related to the area , number of inhabitants, but especially with the use of the land and the arrangement thereof . In the river delta are many towns located along the main artery of communication: Chilia arm Tulcea , Sulina Danube Old or county roads . Vulnerability exposed localities are Pătlăgeanca , Cetalchioi , Sălceni , Plauru , Padina , Chilia Old Tudor Vladimirescu Gorgova , Mile 23 and Malcoci . Old Town is located on land Chilia predeltaic Chilia, and has a compact structure , the high area.

Resulting risk map by combining the hazard map and vulnerability map reveals that agricultural facilities are areas most at risk from flooding . This is reinforced by detailed research within agricultural enclosure Padina . Inside Padina are large areas falling within risk classes medium to high . Zaghen agricultural development , between Tulcea and Malcoci, has a high risk of flooding. Among the localities analyzed Chilia Veche is a special case , in that the majority of the village is at an elevation surface protected from flood waters , which causes no risk for more than 90 % of the village. Similarly happens with Malcoci village . Localities in the west of the river delta have the highest flood risk : Pătlăgeanca , Sălceni , Ceatalchioi , Padina , Tudor Vladimirescu .
The risk of flooding from the river delta decreases from west to east and from the banks of the Danube arms and main channels to the interior Delta . The areas most protected from the risk of flooding from the river delta are the Rosca Buhaiova lake complex and the eastern part of the lake complex Matiţa - Merhei . Municipalities have a specific distribution pattern of local morphology . It depends on the appearance of the terrain , the structure of the village and its pattern . Danube delta has areas of high flood risk , and areas where the risk is low.

Recommendations

Restoration (or Renewed technology) leads to lowering water levels high (if flooded enclosure Padina was calculated an average decrease for the situation in 2006 more than 50 cm) to reinstall the original vegetation to restore soil structure to reinstall the original ecosystems and thus to reduce flood risk . At the same time decrease the costs of :

- Supporting agriculture in areas unfriendly bad ;
- Maintaining a large and linear kilometers of dikes ;
- Defend towns against floods;
- Land infrastructure and facilities useful movements .

Biome Delta is " threatened " by natural evolution . If the current environmental conditions are maintained for a period of time to assist agradare topographic surface normal at lake complexes clogging inside delta streams and sahalelor disappearance and ultimately transform the area into a plain delta delta and then a coastal plain . We can not fight nature walking normally ? At what cost ?

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Datele LiDAR folosite în elaborarea Modelului Numeric al Terenului şi elaborarea lui au fost obţinute ca rezultat al proiectului cu titlul „Elaborarea unui suport cartografic digital de rezoluţie înaltă necesar implementării planurilor, strategiilor şi a schemelor de management în Rezervaţia Biosferei Delta Dunării”. Acest proiect a fost finanţat prin *Programul Operaţional Sectorial „Mediu”* reprezentând documentul de programare a Fondurilor Structurale şi de Coeziune (FSC), care stabileşte strategia de alocare a fondurilor europene în vederea dezvoltării sectorului de mediu în România, în perioada 2007-2013.

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