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ASSESSMENT OF THE ANTHROPOGENIC IMPACT ON THE PLUVIAL FLOODS OF THE RIVERS OF THE REPUBLIC OF MOLDOVA

166.02 ENVIRONMENT PROTECTION AND RATIONAL USE OF NATURAL RESOURCES

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CONCEPTUAL ASPECTS OF THE RESEARCH

Theme actuality. Floods are the most frequent natural disasters, which are recorded on the territory of the Republic of Moldova [23, 32]. Total damages caused by floods during the period 1947-2014 constitute 583 mil. US $ from which losses of 232 mil. US $ were determined by summer floods on big rivers and losses of 331 mil. US $ - over 55% of total - were caused by flash floods generated by heavy rains [32]. Thus, floods of pluvial origin produce the biggest material damages as well as the highest number of victims. Increasing degree of human impact on the environment remains to be one of the main factors determining the flood regime changes.

The importance and actuality of study theme is determined by the significant human pressure on the environment, expressed by urbanization processes, agricultural activities (>70% of the country's territory is used in agriculture, natural lands are preserved only insularly), hydromorphological alterations of the rivers, problems associated with the reservoirs operation, state of flood protection levees, climate change expressed by increasing frequency and intensity of heavy rains as floods generating factors, the need to develop flood management plans at national and basin level, insufficiency of actual studies on the anthropogenic impact on floods and the need to improve the methodological basis regarding maximum runoff. Thus, this theme represents a special interest for research as well as for identification of the solutions to reduce the anthropogenic impact on maximum runoff, as well as the negative effects of floods on society.

The present study is perfectly integrated in research direction chosen by the European scientific community for the scientific decade 2013-2022 within the International Association of Hydrological Sciences (IAHS) "Panta Rhei - Everything Flows: Change in Hydrology and Society" [38]. Also, the research represents a way of arguing the need to move from the traditional *flood defense approach* to the modern one of *integrated flood management*, proposed within the International Flood Initiative [24, p.1, 29]. For the Republic of Moldova, the transition to this approach is of major importance, however integrated flood management system implementation requires not only in-depth research, but also the awareness of the population and decision-makers regarding the importance of flood-prone areas.

Description of current state in the research field and identification of research problems. Research on pluvial flood of the rivers of the Republic of Moldova is based on regional and international methodological principles. The first studies dedicated to maximum runoff were performed by: Slastihin V., Befani A., Gopcenco E., Lalykin N., Melniciuc O. and others [14, 53]. The main content of this research consists of the study and adaptation of empirical, genetic and volumetric methods for determination of computed hydrological characteristics of maximum runoff of the rivers of Moldova and Ukraine. The first attempts for assessment of human impact on rivers runoff were performed in the second half of the 20th century and were consolidated in the form of normative recommendations published in 1986 [56], which were not further developed.

At present, in the national normative documents [3, 4], for evaluation of maximum runoff, two basic groups of methods are included: analysis of hydrological time series and pluvial flood modeling. The first group of methods consists of *time series quality evaluation* by estimation of their homogeneity and stationarity. In case of lack of hydrological data, *reduction and genetic methods* for probable peak discharge modeling are recommended for application. These contain coefficients which allow estimation of the *influence of reservoirs* and *land use* on flood runoff. The specifics of existing models for estimation of *urbanization impact* are based on determination of direct runoff generated by heavy rains by normalization of infiltration losses for various land cover areas of the settlements. The calculation model of pluvial floods runoff from developed territory is based on the reduction or genetic equations structure.

The flood generation process is subject to changes due to human activity, in particular, expressed by *management practices of the river basins*, while the flood wave propagation process is strongly influenced by the anthropogenic impact manifested by *rivers training, hydro-technical constructions* (levees, reservoirs, etc.). Taking in consideration that the problem of identification and understanding of changes in characteristics of the pluvial floods of the rivers of the Republic of Moldova is fragmentarily studied and reflects the scientific experience of the previous decades, and newer methods were not applied, we consider that it is extremely important to develop a scientific-informational basis regarding simulation of flood wave generation and propagation processes for further application in order to evaluate the impacts of climate change, river training, floodplain and land use modifications on flood runoff.

Study aim consists of assessment of changes in pluvial floods characteristics in conditions of anthropogenic impact.

Research objectives: identification and estimation of changes in pluvial flood runoff regime under the influence of anthropogenic activity on the basis of static methods; modeling of anthropogenic impact on flood waves generation and propagation processes of the pilot rivers using hydrological and hydrodynamic models; assessment of flood risk changes in conditions of environmental modifications.

Research methodology. The following methods were used to achieve the purpose and objectives of the study: comparative method, Indicators of Hydrological Alterations, Environmental Flow Components approaches, genetic method, volumetric method, Curve Number method (SCS-CN), JAMS/J2000 hydrological model, HEC-RAS hydrodynamic model. Factorial analysis, GIS, and statistical methods were also applied in the research.

Scientific innovation and originality of the work: For the first time for the territory of the Republic of Moldova, flood runoff characteristics under stationary and non-stationary conditions were estimated and temporal dynamics of pluvial floods under the influence of land cover changes and reservoirs operation were determined. Flash floods, flooding and flood wave propagation potential was calculated and mapped. Using SCS-CN method, volumetric method and JAMS/J2000 physically-based fully distributed hydrologic model the impact of land use and agricultural activity on flood runoff characteristics was demonstrated. Using GIS and HEC-RAS model, the impact of climate change and hydro-technical constructions: reservoirs and levees on flood wave propagation through the river bed and floodplain and the spatial distribution of flood risk was estimated.

The important scientific problem solved consists of assessment of changes in temporal and spatial characteristics of flood runoff of the rivers of the Republic of Moldova caused by the anthropogenic activity.

Theoretical significance. Indicators of Hydrological Alterations and Environmental Flow Components were identified and comparatively analyzed and land use and reservoirs impact on flood runoff characteristics was assessed. Spatial distribution of the indexes of flash floods, flooding and flood wave propagation potential on the territory of the Republic of Moldova was modeled. The contribution of land cover types and agricultural activities in pluvial flood generation was estimated and modifications of flood wave generation and propagation processes under the action of hydrotechnical structures, climate change and land management were evaluated.

Applicative value of the research. Obtained results can be used for development of territorial planning activities for mitigation of maximum runoff, optimization of pluvial floods management, implementation of structural and nonstructural flood protection measures. Furthermore, the results can serve as methodological basis for improvement of national normative documents for determination of computed hydrological characteristics.

Scientific results proposed for defense:

- assessment of temporal dynamics of flood runoff characteristics of the rivers of the Republic of Moldova in conditions of land cover changes and reservoirs operation;
- mathematical and cartographic models (maps) of indexes of flash floods, flooding and flood wave propagation potential as well as of flood runoff and estimation of particularities of their regional distribution;
- improved mathematical models for calculation of flood runoff characteristics in stationary and non-stationary conditions as well as of flood volumes which are used to assess the influence of land cover types of pluvial flood generation;

- quantitative assessment of genetic model components for calculation of probable peak discharge, in particular, estimation of actual values of flood hydrograph shape coefficient and of coefficient of peak discharges control under reservoir impact;
- hydrological and hydrodynamic models of flood runoff generation and flood wave propagation processes simulation and their application for estimation of the effect of land cover changes on temporal dynamics of pluvial floods at local and regional level and for assessment of impact of reservoir, levees and climate change on flood wave dynamics and spatial distribution of flood hazard/risk areas.

Approval of scientific results. Scientific value of the research was confirmed at national and international scientific conferences: The Dniester river basin: environmental issues and management transboundary natural resources (2010, Tiraspol), Water – History, Resources, Perspectives (2010, Chisinau), International Conference of Young Researchers (VIIIth edition) (2010, Chisinau), Academician Leo Berg - 135 years (2011, Tiraspol), Географические исследования: история, настоящее, перспективы (2011, Harcov), Екологічні проблеми Чорного моря (2011, Odessa), Актуальні проблеми сучасної гідрометеорології (2012, Odessa), Vulnerability and risk assessment using G.I.S. (2012, 2016, Cluj-Napoca), V Danube Academies Conference (2014, Chisinau), Modern Hydrometeorology: Topical Issues and the solutions (2014, Odessa), GIS (2014, Chisinau; 2016, Cluj; 2017, Iashi), Conferinţa ştiinţifică anuală a Institutului Naţional de Hidrologie şi Gospodărire a Apelor din România (2015, București), Mediul și dezvoltare durabilă (IIIrd edition) (2016, Chisinau), International Exposition and Summit on the occasion of the World Geographic Information Systems Day (2016, Istanbul), Biodiversity in the context of climate changes (2016, Chisinau), Present environment and sustainable development (XIIth, XIIIth edition) (2017, 2018, Iashi), Transboundary Dniester river basin management: platform for cooperation and current challenges (2017, Tiraspol), American Geophysical Union Fall Meeting (2018, Washington).

Implementation of scientific results. Digital maps on pluvial flood runoff were implemented by the Districts Councils of Glodeni and Faleshti for development of urban and territorial planning and management of the Camenca river basin. The obtained results were used for the sustainable management of water resources and hydrological risk situations, reservoirs operation optimization by the Basin Water Management Authority, ”Apele Moldovei” Agency.

Publication on the thesis topic: The research results were published in 23 scientific papers including: chapters in monographs - 1, articles in: ISI journals - 2 (2 without coauthors), category B journals - 2 (2 without coauthors), category C journals - 3 (1 without coauthors), articles in various scientific journals - 12 (7 without coauthor), theses at scientific forums - 3 (2 without coauthors).

Key words: pluvial floods, hydrological and hydraulic modeling, anthropogenic impact, land cover, reservoirs, GIS.

Structure and volume of the thesis: The thesis consisted of introduction, four chapters, general conclusions and recommendations, 264 references, 150 pages of basic text, 165 figures, 17 tables, 191 annexes, declaration of responsibility assumption and author CV. The thesis is written in Romanian and English language.

THESIS CONTENT

In **Introduction** the importance of studying the pluvial floods regime and the anthropogenic impact on it is emphasizes, aim and the objectives of the research are formulated, the scientific innovation, the theoretical significance and the applicative value of the thesis are justifies, the chapters are briefly described.

1. PLUVIAL FLOODS IN CONDITION OF ANTHROPOGENIC IMPACT (LITERATURE REVIEW)

1.1. Flood wave generation and propagation processes

Human activity causes changes in flood runoff generation and propagation processes which are manifested in a differentiated way within the river basin (r. b.). Natural conditions of the upper part of the basin in combination with torrential rains cause generation of fast slope runoff resulting in flash floods, the effect of which can be amplified by deforestation or excessive overgrazing. In the middle part of the basin where human activity is more prominent, deforestation, overgrazing and agricultural activities lead to intensification of maximum slope runoff. Urbanization reduces water retention capacity by vegetation as well as soil infiltration, processes which generate urban floods which, in case of absence of an effective *rainwater drainage systems*, cause considerable damage and casualties. In the downstream part of the basin, *agricultural activities* practiced in river floodplains become vulnerable to pluvial floods due to very large expansion of their flood-prone areas. Increasing urbanization process and low costs of terrain in the flood-prone areas which attract, in most of the cases, the needy people, determine the increase of population's exposure and vulnerability to floods. Propagation of the flood wave from the upstream part of the basin in combination with local floods or backwaters creates conditions for formation of complex floods which, usually, remain for longer periods from several days to several weeks. The lack/inadequate state of floods defense *hydrotechnical structures* can cause rivers overflowing and as a consequence enormous economic and social damage [modified from 16, p.10]. As a result of evaluation of flood wave generation and propagation processes in conditions of anthropogenic activity, it was estimated that modification of flood regime is caused by:

- Anthropogenic activities which take place on the Earth surface
  - Changes at bazinal level: deforestation, urbanization, etc.;
  - Floodplain arrangement activities (construction of reservoirs, levees, etc.).
- Changes that take place in climatic system
  - Variation/changes of climate caused by human activity.

The specificity of pluvial flood generation processes differs both at basin level (the most devastating being the complex floods), as well as at the size of the river basin itself, so that the environmental changes lead to more pronounced changes of flood characteristics generated within small river basins followed by medium and much less the large ones. However, the relationship between flood behavior in headwater catchments and the flood behavior of entire river basin is often complex and sometimes imperfectly understood [45, p. 97].

1.2. Evaluation of actual level of flood runoff research

Research on anthropogenic impact on pluvial floods was prompted by the rapid growth of population (and, hence, pressures on environment) as well as development of modern hydrology, especially, for last 150 years.

An overview of the size and frequency of catastrophic floods on the rivers of the Republic of Moldova is provided by both *hydrological monitoring data* as well as *archival documents*. A big number of researchers: Melniciuc O., Boian I., Cazac V., Mihailescu C., Bejenaru Gh., Lalîkin, N., Arnaut N., Shvets V., etc. dedicated a set of publications to *description and analysis of information about pluvial floods* and their characteristics. Studies on pluvial floods generation processes were performed by Slastihin V., Befani A., Gopcenco E. Lalîkin N., Melniciuc O. [14, 53, 54]. The results of this research were integrated in the national normative documents existed at the moment [3, 4].

The attempts for development of the methodology for estimation of the impact of *runoff regulation, urbanization and agricultural activities* on the regime of pluvial floods of the rivers of the Republic of Moldova can be found in publications of Lalykin N., Melniciuc O., where the authors recommend to integrate in the operational structure of equations for evaluation of flood runoff a set of coefficients for determination of mentioned activities impact [14, 53].

Assessment of *climate change on floods* of the rivers of Europe, including those of the Republic of Moldova, performed recently basing on projections of the Vth report of the IPCC expert group [19, p. 2253], shows that the peak discharges of 1% probability tend to increase towards the end of the century, especially a higher increase being specific for the internal rivers of the country located in the central and northern part.

One of the most effective methods of flood protection is the *reservoirs* (res.) *operation*. But despite the presence of a big number of ponds and reservoirs (over 3000), they play a minor role in flood protection system on small rivers of the country [55, p. 85]. In the sense of controlling the maximum runoff of large rivers, the most efficient is the Costeshti-Stynca res., built on the Prut river (r.), which must reduce the peak discharge of 1% probability by 76% and the one of 0.1% - by 40%. The Dubasari res. located on the Dniester r. has a minor effect on regulation of rare probability discharge (0,1-1%), reducing the peak discharge by 4-7% [53, 55].

Development of research at national level and performing construction and/or reconstruction activities of hydro-technical structures designed to protect settlements and agricultural lands from flooding is mainly driven by the damage caused by floods. Thus, as a results of destructive effects of the floods of '40 and '70 (1969) of the last century, reservoirs and levees were constructed on the Dniester, Prut, Byc, Botna etc. Catastrophic floods on small and medium sized rivers which occurred in 1991, 1994 resulted in development of flood protection scheme for settlement of the Republic of Moldova [10]. 2008 and 2010 floods accelerated occurrence and development of extensive studies in the field of floods [5, 6, 42], for which new methods and special software (HEC-RAS, InfoWorks) were used, fact that constituted a new stage in research and evaluation of flood runoff.

1.3. Classification of methods for evaluation of anthropogenic impact on pluvial floods

In the literature for assessment of flood regime changes, two main methodological principles are recommended: analysis of time series of main hydrological characteristics and modeling of pluvial flood generation processes and flood wave propagation trough the floodplain [3, 4, 24, 25, 27]. First group of methods includes *methods of direct assessment* of flood regime changes based on analysis of data from monitoring network. In this sense, the most efficient approaches are Indicators of Hydrologic Alteration, Environmental Flow Components [51]. Hydrological information can be analyzed also based on the approaches (1) Paired-Before–After Control–Impact, (2) Before–After, (3) Control–Impact, (4) Hydrological Classification and (5) Predicted Hydrological indices [41].

Another group of methods for assessment of anthropogenic factors impact on pluvial runoff includes *indirect methods* for pluvial floods generation and propagation processes modeling. The big number and differentiated configuration of hydrological models is due to the many objectives for which they were created. Complex studies of human impact on the maximum runoff can be performed by application of hydrological models that integrate both spatial and mathematical models and can represent, in a clear way, the whole range of factors that determine flood generation. Well-known hydrological models are the following: Wasim-ETH, SWAT, MIKE SHE, LISTFLOOD, JAMS/J2000 etc. [22, 37, 49]. Commonly used hydrodynamic models are considered: MIKE11/21, HEC-RAS, LISFLOOD-FP, TELEMAC, SOBEK [37, 49].

2. METHODS AND MATERIALS OF RESEARCH

2.1. Research strategy

Analyzing the world and national research centers experience in the study of the anthropogenic impact on pluvial floods, it was found that, at present, there is no single methodology recognized as mandatory or recommended in this field. However, on the basis of evaluation of the international research results and the local possibilities, a set of basic methodological approaches for identification of anthropogenic activity effect on generation and propagation of the pluvial floods on the rivers of the Republic of Moldova were established and applied. These were based on the use of methods of statistical analysis of hydrological data, indexes for estimation of flash floods and flooding potential, on the application of classical mathematical models as well as of complex hydrological and hydrodynamic modeling.

2.2. Study areas

Identification of study areas (of rivers and their basins) was performed based on evaluation of flood runoff generation and propagation processes, existing database, methods for estimation of maximum runoff, river length, river basins areas, the share of land cover types. As a result, for study of flash floods elementary river basins (delineated in semi-automated way) (fig. 1) and elementary territorial-administrative units (communes) [15] were considered. A more detailed analysis of the land use impact on pluvial floods was performed for 8 pilot rivers (basins) (fig. 2) and 102 tributaries. Assessment of flood wave propagation potential, of probable peak discharges and of flood volumes was performed on example of 50 ungauged pilot rivers (fig. 3), and changes of flood wave dynamics in details was evaluated on the example of the Dniester and Byc rivers.

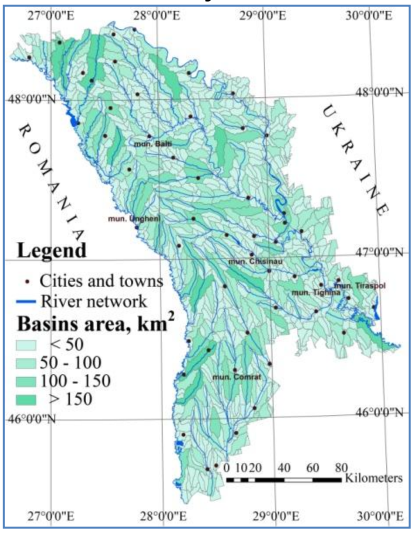

Fig. 1. Small rivers basins area

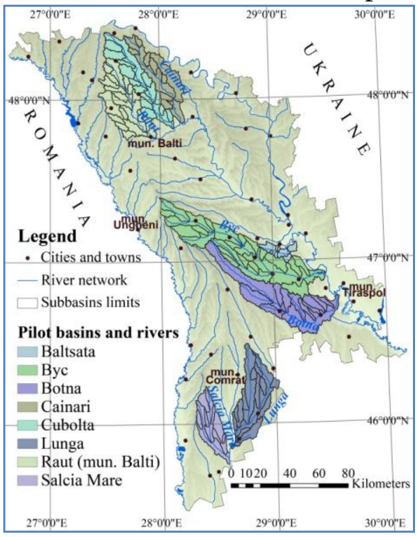

Fig. 2. Pilot rivers basins

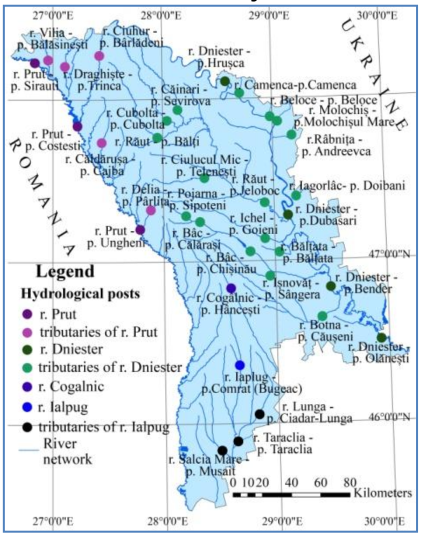

Fig. 3. Selected pilot rivers and hydrological stations [based on 9]

2.3. Direct methods

Methods of hydrological time series quality assessment

Hydrological characteristics time series quality was estimated by testing its stationarity and homogeneity. Homogeneity evaluation was performed using Fisher's statistic criteria, described in national standard [3]. To estimate the random functions stationarity, the autocorrelation coefficient was used recommended by [53].

Methods of determination of computed hydrological characteristics

For estimation of *empirical* probability of flood characteristics values, the Weibull equation was used, and of the *theoretical* one - the asymmetric binomial distribution or Pearson type III and three-parametrical gamma-distribution according to Kritski-Menkel ordinates [3]. Parameters required for data statistical analysis are as follows: average value of flood runoff characteristics; coefficient of variation C_v, coefficient of skewness C_s, random mean square error ε, coefficient of autocorrelation $r_{(\tau)}$.

Hydrological alteration indicators

From all existing approaches, the best way to assess the anthropogenic impacts on flood runoff of the rivers of the Republic of Moldova is analysis of hydrological information for pre- and post-impact, pre/post-control periods. From this considerations, there were described and recommended for utilization the approaches: Hydrological Alteration Indicators and Environment Flow Components [51] and alternative indicators such as coefficient of peak discharge attenuation *(K)*, coefficient of hydrograph shape and others.

2.4. Static methods

Indexes of flash flood, flooding, flood wave propagation potential

Assessment of potential for generation and propagation of floods of the rivers of the Republic of Moldova was realized by spatial combination of 19 natural and anthropogenic factors classified according to runoff potential and application of Flash Flood Potential Index (*FFPI*) [44], Flooding Potential Index (*FPI*) [50], Flood wave Propagation Potential Index (*FPPI*). Factors classification was performed according to their impact on the surface runoff generation by attribution of a score from 1 (low potential) to 5 (high potential). Weighted values of each factor were obtained by estimation of the share of surfaces occupied by different classes, integrated into Decision Making

Matrix in Microsoft Excel [21]. Mapping and derivation of needed factors as well as indexed modeling were performed in ArcGIS, QGIS and SAGA GIS environment [20, 40, 43].

SCS-CN method

The SCS-CN model [46] was used for assessment of regional variation of flood runoff within the elementary river basins and elementary territorial-administrative units of the Republic of Moldova. Taking in consideration that all the factors that are integrated in the SCS-CN model (soil, precipitation, land cover) as well as calculated characteristics can be spatially represented using GIS techniques, utilization of this model is suitable for evaluation of human impact on runoff expressed by land cover changes, modification of soil texture and moisture conditions, agricultural activities, climate variations.

Genetic method

According to [3], modeling of the probable peak discharge is performed using genetic method, widely applied at regional and local level for ungauged rivers [57, 58]. It integrates the coefficients that reflect the anthropogenic activity. The impacts of *agricultural activities on flood runoff* can be expressed from the perspective of changes in slope runoff that is determined by the variable that establishes the slope runoff hydrograph shape *n*, integrated into equation for calculation of coefficient of irregularity in time of slope runoff. Another anthropogenic factor, which is included in this model, reflects *reservoirs operation*, expressed by a specific coefficient which is based on information on spatial characteristics of reservoirs situated in the river basins.

Volumetric method

Runoff volume is a value that sums up the volumes generated on all surfaces within the river basins. According to recommendation from [4, 17], it is represented as a product between the flood runoff depth and the river basin area. In turn, the flood runoff depth is estimated by the product of territory surface, the function of reduction in time of torrential rain, and weighted mean coefficient of the runoff from urbanized area η_S [4]. In the present research, for evaluation of the contribution of different land cover types in generation of pluvial flood volume, the traditional equation of η_S estimation was substituted with the following [18, p. 9]:

$$\eta_S = \frac{\left(PP_{\mathrm{m},\%} - 0{,}2 * Sp\right)^2}{PP_{m,\%}\left(PP_{m,\%} + 0{,}8 * Sp\right)} \qquad (1)$$

$PP_{m,\%}$ - daily maximum sum of precipitation of certain probability *P*, %, mm

Sp - potential for water retention, calculated using SCS-CN model, mm

2.5. Dynamic models

Simulation of flood runoff generation processes using JAMS/J2000 hydrological model

In the JAMS/J2000 hydrological model, simulation of runoff generation processes is based on the water balance equation as well as on temporal and spatial data of environmental components. First phase consists of development of spatial representations of environmental components by delineation of the Hydrologic Response Unit (*HRU*) in GRASS HRU web service, as well as of meteorological data by their interpolation in the special module in J2000 model. Subsequently, the losses/storages of rainwater in the river basins are estimated by evapotranspiration, retention in the soil, vegetation, geologic substrata. The last stage consist of determination of final result: slope and river runoff [30, 34]. Model calibration is realized by combination of both manual methods as well as automated. For evaluation of model quality Nash-Sutcliffe (*E*) efficiency function as well as its logarithmic form (*lnE*), the coefficient of determination of modeled and measured data correlation (R^2) and the mean error in % (*PBIAS*) were used [39].

Simulation of flood wave propagation processes using HEC-RAS hydrodynamic model

In the HEC-RAS hydrodynamic model, flood wave simulation is based on virtual representation of the floodplain and the river flow modeling using various propagation methods: the momentum, continuity equations, etc. [28]. Application of hydrodynamic simulation is necessary for modeling of the flood hazards and its characteristics: spatial distribution, water depth and velocity, inundation duration for the scenarios of presence and absence of flood protection levees, as well as for evaluation of climate changes impact on flood risk. Models calibration and validation was performed using the same functions as in case of hydrological modeling.

Flood risk is a function of hazard, exposure and vulnerability of population and material goods to floods occurrence [8, 36]. In the present study, in the risk equation, the hazard is represented by the intensity of the flood (fig. 4) of 10, 5, 1, 0.5, 0.1%. Determination of exposure to floods was made on the basis of overlapping the land cover and flood hazard area, and the vulnerability to floods was identified based on assessment of material damages (fig. 5) [42]. According to this principle, it was estimated that the category of high vulnerability to floods should include the rural and urban areas, the category of medium vulnerability - arable land as well as vineyards and orchards, and the one of small vulnerability - lands covered by forest, shrubs and grassland. Finally, overlapping the spatial information obtained from the process of flood intensity and flood vulnerability assessment resulted in the flood risk determination that was classified based on the matrix in table 1. The number of affected people was estimated as a product between population density and settlement flood-prone area. According to [42], severely affected people will be considered those located in the area where the product between water depth and velocity (to which 0.5 was added) would be in the limits of 1.5 and 2.5, and the very severely affected people will be those of the area where this product would be > 2.5.

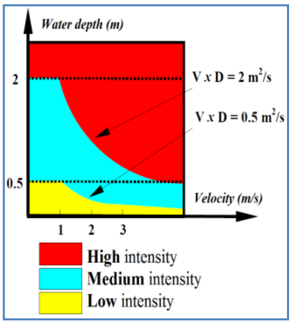

Fig. 4. Flood intensity [18, p. 28]

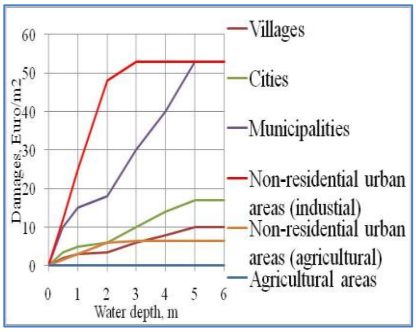

Fig. 5. Relationship of flood depth and caused damages [performed based on 42]

Table 1. The matrix of flood risk assessment

Flood risk		Vulnerability to flood		
		high	medium	low
Flood intensity	high	high	high	medium
	medium	high	medium	low
	low	medium	low	low

2.6. Research materials

Application of the methods described above can be done only in case of availability of a particular database, the complexity of which depends on the applied methods. For utilization of methods for FFPI, FPI, FPPI assessment, only spatial databases of the environment and river network components are needed, while hydrological modeling requires both spatial as well as temporal data and also a detailed knowledge of runoff generation processes. Temporal database needed for hydrologic study in J2000 consists of daily time series of: air temperature, precipitation, wind speed, air relative humidity, sunshine duration and river runoff [1, 2]. For creation of *HRU* the following is used: land cover (*LU*) [7], digital elevation model (*DEM*) [47], soils [7] and geologic substrata [52]. For simulation of flood wave propagation, the *DEM* realized using LIDAR within the project [42] was used. Models calibration and validation were performed using the database from gauging stations of the monitoring network (fig. 3).

3. ESTIMATION OF THE ANTHROPOGENIC IMPACT ON FLOOD RUNOFF USING DIRECT AND STATIC MODELS

3.1. Qualitative analysis of hydrological information

Estimation of temporal variation of pluvial floods characteristics

Based on the hydrological data analysis, the average values of maximum runoff characteristics were calculated as well as the most significant pluvial floods estimated as a function of peak discharge and its empirical probability (≤15%) were emphasized. The largest floods are recorded on large rivers the Dniester and the Prut, followed by the medium and small-sized rivers.

The trend of temporal change in annual peak discharges varies from one river to another. A downward trend is specific for the most of monitored rivers, with particular emphasis on the left-bank tributaries of the Dniester river as well as on the Ciulucul Mic and the Cogylnic rivers. The flood runoff depth differs from values of over 22 mm for the large rivers and under 10 mm - for small and medium-sized ones. The correlation of rising limb time and the total flood duration indicates an obvious logical dependence between these characteristics, which denotes that 25-35% is flood rising limb time and 65-75% is falling limb time from the total flood wave duration. The month of maximum occurrences of flood events is now July for the northern part of the republic, June for the central and southern regions. Also, it was observed that, in last decades, pluvial floods occur in their nonspecific months such as those of spring or autumn, as well as pluvial floods occurrence has intensified in the other months than the month with highest number of flood events.

Calculation of hydrological characteristics in stationary and non-stationary conditions

Using existed hydrological times series, the pluvial floods characteristics in stationary and non-stationary conditions were estimated. As a result, *the coefficient of change of the flood runoff characteristics under the action of anthropogenic activity* k_a was developed for estimation of their changes in case of stationarity condition failure based on calculation of autocorrelation coefficient ($r_{(\tau)}$), random mean square error (ε, equal to 10%), time series variance (σ_x) and number of years of observations (n):

$$k_a = Q' / Q'' \qquad (2)$$

where:

Q' - average value of peak discharges calculated in stationary conditions ($r_{(\tau)} = 0$)

Q'' - average value of peak discharges calculated in non-stationary conditions ($r_{(\tau)} \leq 0,5$):

$$Q' = \frac{\sigma_x}{\varepsilon\sqrt{n}} \qquad (3) \qquad\qquad Q'' = \frac{\sigma_x}{\varepsilon\sqrt{n}}\sqrt{\frac{1+r_{(\tau)}}{1-r_{(\tau)}}} \qquad (4)$$

Comparison of result of analysis of flood runoff in stationary and non-stationary conditions showed that the changes of peak discharges are of 4%, and of flood runoff depth - of 12%.

Determination of computed hydrological characteristics

For estimation of computed hydrological characteristics for 26 monitored rivers, initially, statistical parameters were calculated. Thus, coefficient of variation C_v and of skewness C_s constitute 0,85-2,22 and, respectively, 2,2-7,8 in case of peak discharges, 0,5-1,9 and 1,25-7,4 for flood runoff depth, and 0,15-1,25 and 0,45-6 from summer runoff depth. Errors >25% are recorded, mostly, in case of rivers in the southern part of the country. Error values indicate a rather unsatisfactory confidence level of flood runoff characteristics for $C_v \geq 0.5$. Subsequently, peak discharges, flood runoff depth of 0,001, 0,01, 0,1, 0,3, 0,5, 1, 3, 5, 10% probability were calculated as well as coefficients of transfer from one probability to another were estimated. Also, spatial representations of 1% flood runoff depth as well as of 1% elementary specific discharge were developed.

3.2. Assessment of changes in pluvial floods characteristics based on monitoring data

Land use and pluvial floods on small rivers

The impact of land use on flood runoff generated on small rivers was performed by analyzing of hydrological information from the Baltsata water balance station. In its limits, for the 1954-1994, two pairs of runoff stations (platforms) were monitored. These are characterized by the same natural conditions, the difference being only the land cover. Also, there were considered hydrological time series of Stantsionyi, Vishnevyi, Vinogradnyi, Sagaidachnyi rivers (the Baltsata r. tributaries) as well as detailed annual description of the land use. For identification of certain changes in flood runoff under the impact of land use, 347 hydrographs were analyzed. It was found that for stations 3 and 4 which were covered by pasture the entire period, the values of average discharge are lower by 35-70 times, of average peak discharge - by 50-85 times, of flood volume and depth - by 30-53 times compared the ones of stations 1 and 2 whose area was used as arable land. Flood runoff duration is bigger by 1.5 times for the stations 3 and 4, which leads to a reduction of the slope runoff velocity and of disastrous effect of floods. Comparative analysis of hydrological characteristics of the Baltsata r. tributaries did not result in identification of major changes in periods of different *LU*.

Controlling the pluvial floods by hydrotechnical constructions

Assessment of reservoirs impact was performed by analysis of hydrological information pre/post-impact, pre/post-control existed for large and medium-sized rivers. The evaluation of four reservoirs impact on floods was realized: the Novodnestrovsk (partially) and the Dubasari reservoirs situated on the Dniester river, the Costeshti-Stynca res. from the Prut river and the Ghidighici res. (partially) from the Byc r. The changes in peak discharges and in the shape of flood wave hydrographs for the period before and after reservoirs construction, as well as from the gauging station from the upstream and downstream parts of the reservoirs, for three pilot-rivers, are represented in figures 6, 7, 9, 10, 12, 13. Average value of *K* of the floods on the Dniester r. in natural conditions (1887-1955) is equal to 0,4, which during the Dubasari res. operation (1956-1982) increases to 0,58 and decreases to 0,52 after the Novodnestrovsk res. construction. *K* estimated for the Prut r. is 0,41 before the Costeshti-Stynca res. and is reduced to 0,3 after beginning of its exploitation, fact that shows that flood management on the Prut r. is more efficient than on the Dniester r. Under the impact of the Novodnestrovsk res. probable peak discharges of 0,1-20% from Hrushca st. decrease with 35-41%. Distribution of probable discharges from Bender st. for 3 periods, however, show an increase of peak discharges of medium and low probability (0,1-10%) with ~ 22-44% in the years of only the Dubasari res. functioning, and with 1-21% for the time of entire flood protection systems, in comparison with the period of natural runoff. Comparative analysis of probable peak discharges from the stations of the Prut r. showed that discharges of 0,1-10% from the station in the upstream are 3,5-8 times higher than those of the stations from the downstream. Distribution of probable peak discharges of the Byc r. is represented in figure 14. The reservoirs impact was evaluated and by analyzing the changes of characteristics of Environmental Flow Components. The frequency of high-flow pulses and small floods is represented in figures 8, 11, 15.

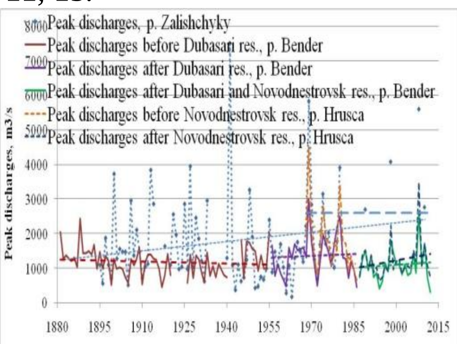

Fig. 6. Flood peak discharge, the Dniester r.

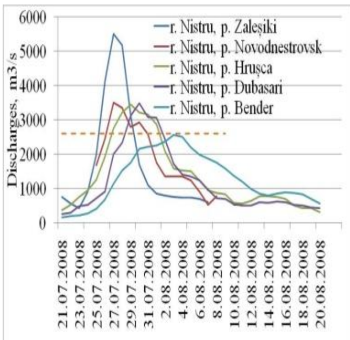

Fig. 7. Flood hydrographs of 2008, the Dniester r.

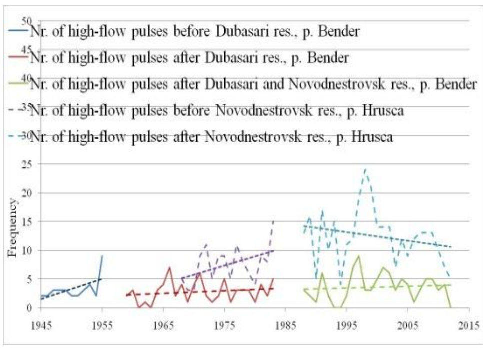

Fig. 8. Number of cases of small floods and high flow pulses, the Dniester r.

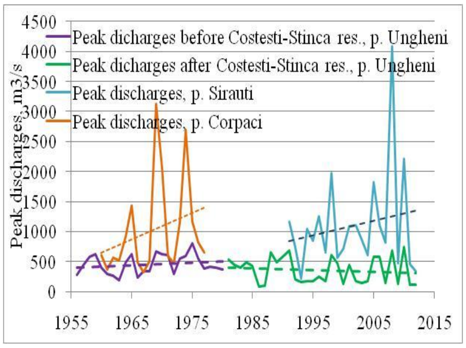

Fig. 9. Annual peak discharges of pluvial floods, Prut r

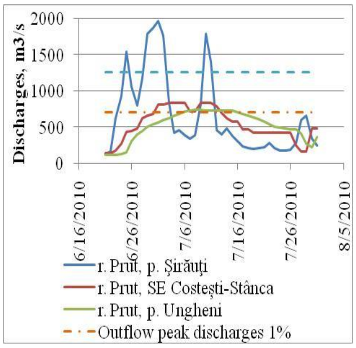

Fig. 10. Flood hydrographs of 2010, the Prut r.

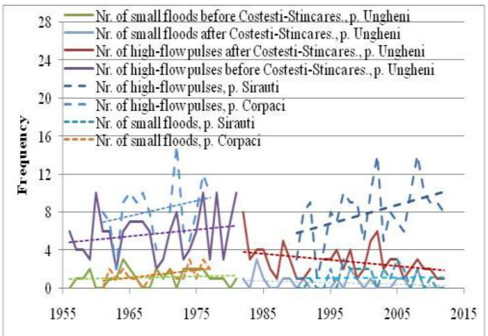

Fig. 11. Number of cases of small floods and high flow pulses, Prut r.

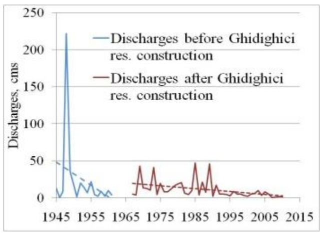

Fig. 12. Annual peak discharge of pluvial floods, Byc r., Chisinau st.

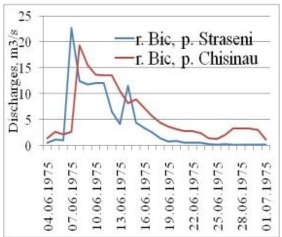

Fig. 13 Flood hydrographs of 1975

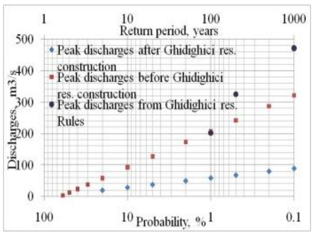

Fig. 14. Distribution of peak discharges of different probabilities, Byc r., Chisinau st.

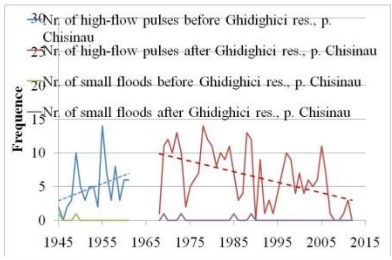

Fig. 15. Average peak discharge of small floods and high flow pulses, Byc r.

3.3. Potential of generation, accumulation and propagation of pluvial floods

In order to estimate flash floods and flooding areas, indexes were developed that can be easily and fast applied and can give a preliminary understanding of hydrologic processes that take place during pluvial floods occurrence. For modeling of *FFPI* and *FPI* the following equations were developed and applied:

$$FFPI = (PP_{1\%} * 1{,}8) + (Sl * 1{,}0) + (LS * 0{,}8) + (CI * 1{,}5) + (PC * 1{,}4) + (ST * 1{,}8) + (LU * 1{,}6) \quad (5)$$

$$FPI = (PP_{1\%} * 1{,}8) + (Sl * 1{,}9) + (CI * 1{,}4) + (TWI * 1{,}4) + (ST * 1{,}8) + (LU * 1{,}6) \quad (6)$$

where: *LS* - slope length and steepness factor *PC* - profile curvature *CI* - convergence index *Sl* - slope *TWI* - topographic wetness index *ST* - soil (texture) *LU* - land cover

According to the same principle applied for the estimation of *FFPI* and *FPI*, the *FPPI* was developed and applied for 50 pilot-rivers. The natural and anthropogenic factors characterizing the main riverbed were chosen and classified: river slope, gradient, sinuosity, share of river length converted into reservoirs, share of embanked river, the share of river lengths passing trough settlements and forest as well as the maximum precipitation of 1% ($PP_{1\%}$).

It was estimated that aprox. 29% from the country's territory is characterized by high and very high potential for flash floods generation (fig. 16). For the 30% from the country's area the high and very high inundation potential is specific (fig. 17), characteristic zones being rivers floodplains. *FFPI* and *FPI* are, in general, medium for aprox. 80-90% of the river basins and communes. It was established that 56% of studied rivers indicates a medium flood propagation potential, 36% are characterized by high, 4% - by the very high one. Most of rivers with high *FPPI* are situated in plateau region, in the central and southern part of the country (fig. 18).

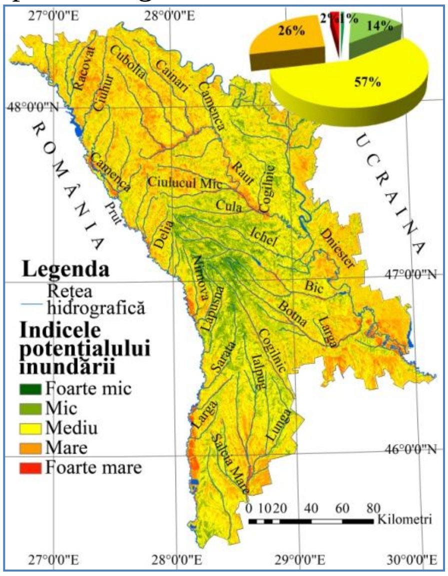

Fig. 16. Flash flood potential Index

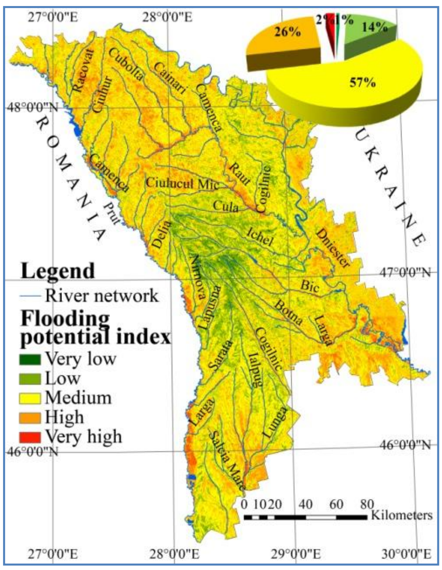

Fig. 17. Flooding potential Index

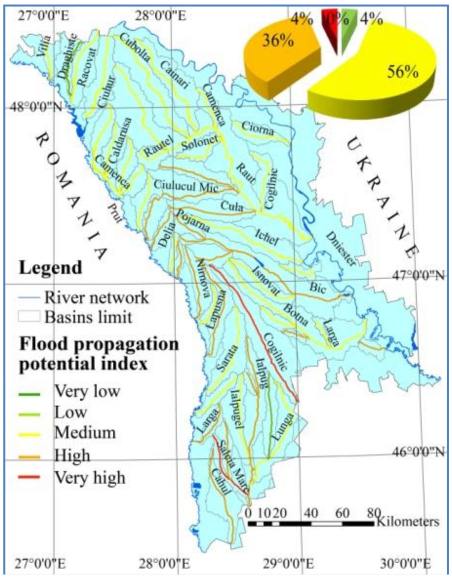

Fig. 18. Flood wave Propagation Potential Index

3.4. Regional variation of flood runoff depth determined by anthropogenic activity

Spatial distribution of flood runoff depth under the impact of natural and anthropogenic factors

A way for estimation of the land cover impact on the pluvial floods is application of the SCS-CN model. Initially, the model was validated on the example on the 26 rivers, with the presence of hydrological information. Subsequently, the model was applied on example of elementary river basins and communes for the case when the maximum precipitation would be of 1% probability values, and in order to avoid the impact of its spatial distribution, it was equaled to 100mm for the entire country. For both scenarios, soil moisture was considered as low (*ASMI*), medium (*ASMII*) and high (*ASMIII*) and land cover remained constant. As a result, 6 spatial models (maps) were obtained, based on which, the average values of the flood runoff were estimated. For scenario I and II these are 31,4 and 24 mm in case of dry soils, 90,7 and 79,3 mm for wet soil, and equal to 63,8 and 53,5 mm for soil average moisture condition. Obviously, the most flood-affected regions are those where maximum precipitation values exceed 150mm (fig. 19). Soil moisture conditions as well as soil structure have a important impact on flood runoff amount. Its values can increase from 30 to 60% in case of high moisture conditions caused by antecedent precipitation or by irrigation process, and, respectively, can decrease by 35-65% in case of completely dry soil. The continuous process of soil compaction due to agricultural technique influence, will lead to an increase of the flood runoff by about 26% under *ASM II* conditions, 38% in case of *ASM I* and 17% for soil with *ASM III*. Approximately the same rules are maintained in the case of flood runoff modeling using 100mm precipitation (fig. 20). It was determined that flood runoff generated in the basins and communes where urban zones occupy ½ of the area is 2-3 times higher than the one generated in areas where natural vegetation prevails (fig. 21).

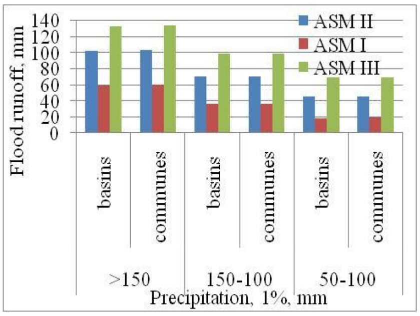

Fig. 19 Flood runoff in condition of maximum precipitation impact

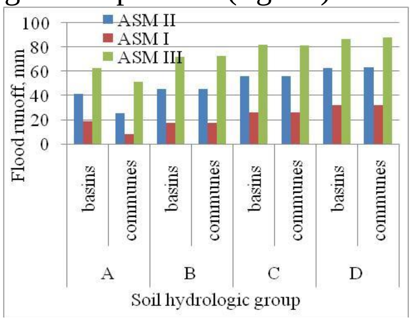

Fig. 20. Flood runoff (PP=100 mm), influenced by soil texture

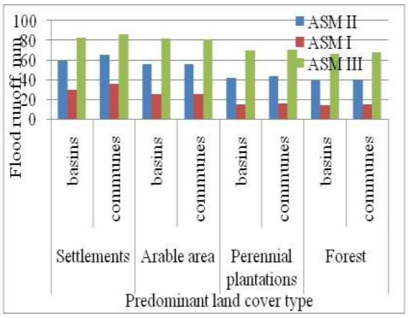

Fig. 21. Flood runoff in conditions of PP=100mm, under different LU

In order to estimate the relationship between land cover and flood runoff, an attempt was performed to construct the multiple regression equation (using STATGRAPHICS program [48]) between maximum runoff depth, the share (*Pr*) of *LU* types, which determine surface water retention, as well as the value of 1% probability rainfall, estimated for 789 small basins. Another multiple regression equation was constructed for the case when the precipitation value was equaled to 100mm. The equations for the 2 cases took the form of 7 and 8. For correlation of flood runoff values estimated using SCS-CN and 7 and 8 formulas, the corresponding graphs have been constructed, showing a relatively high relationship between modeled characteristics [32]. Thus, the proposed equations can be used to assess the flood runoff variation under the impact of land use change within river basins or other areas (such as communes).

$$Y_{reg\,1} = -118.841 + 0.622161 * Pr_{Forest} + 0.946481 * Pr_{Grassland} + 0.973797 * Pr_{Villages} + 0.587012 * Pr_{Vineyards} + 0.882476 * PPm1\% + 0.891529 * Pr_{Arable} + 0.756157 * Pr_{Orchards} + 1.04003 * Pr_{Towns} \quad (7)$$

$$Y_{reg\,2} = -25.2683 + 0.920384 * Pr_{Villages} + 0.975952 * Pr_{Towns} + 0.58122 * Pr_{Forest} + 0.899814 * Pr_{Grassland} + 0.542697 * Pr_{Vineyards} + 0.83569 * Pr_{Arable} + 0.692535 * Pr_{Orchards} \quad (8)$$

Assessment of the impact of *the land use change over the last 30 years* (1982 - 2013) *on flood runoff* was performed for 8 pilot-rivers and 102 tributaries. It was calculated that the flood runoff increase is specific for subbasins situated in central part of the Byc r. b., where the extension of urban area is observed, and the decrease is characteristic for subbasins from Botna and Cainari r.b., where abandoned arable terrains were transformed into pastures and shrubs. At local level, significant increases and decreases in flood runoff with -94-+85.6 mm (-67-56.7 mm for dry soils, ± 99 mm for wet soils) were estimated (fig. 22-24).

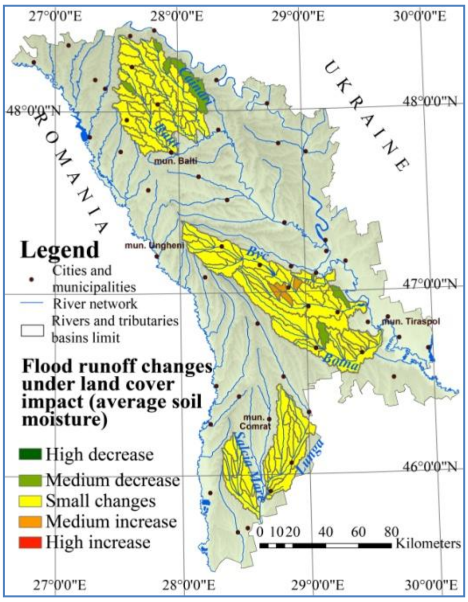

Fig. 22. Flood runoff changes under LU impact, when ASM II

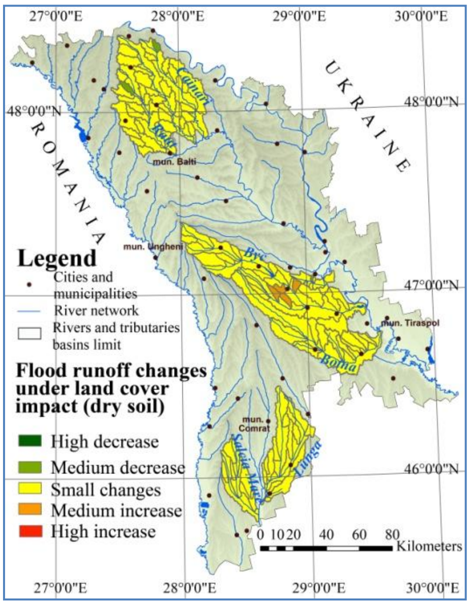

Fig. 23. Flood runoff changes under LU impact, when ASM I

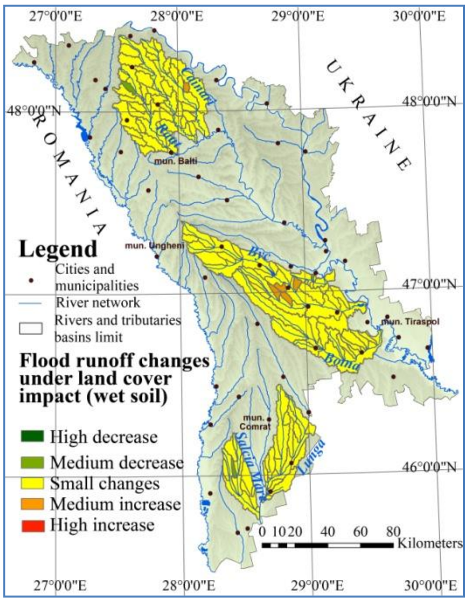

Fig. 24. Flood runoff changes under LU impact, when ASM III

As a result of the analysis of land cover changes impact on the maximum runoff, it was determined that essential differences during the last 30 years were not observed for the medium-sized rivers and their tributaries, however, it is significant at the local level. In spite of the fact that in some small river basins there are quite large changes in the share of different land cover types, the flood runoff changes very little.

3.5. Peak discharge modeling in conditions of land use and reservoirs operation impact

Land use influence

Within the genetic method, assessment of *LU* impact on flood runoff is performed by calculation of flood hydrograph shape *n*. In the national normative document *n* is 0,4 [3]. Based on the analysis of information from runoff stations and tributaries of the Baltsata r. it was identified that this value corresponds to hydrographs that are formed especially on arable terrains. Also, it was found that in case of the land cover diversity, hydrograph shape value has increased to 0,5-0,7. As a result of a numerical experiment, it was estimated that this fact would contribute to the decrease of elementary specific discharge by 14-30% which would determine the reduction of costs of potential hydrotechnical constructions, for which these calculations are needed. Thus, identification of a method for determination of flood hydrograph shape was considered important. In order to extrapolate the *n* value for larger river basins, the multiple regression equation between *n* and different land use types shares presented in the limits of the basins the Baltsata water balance station was determined using STATGRAPHICS software [48]:

$$n = 1.55701 - 0.046558 * Slope - 0.0318469 * Pr_{Grassland} + 0.00070026 * Pr_{Grassland} \text{\textasciicircum}2 - 0.0167192 * Pr_{Arable} + 0.00009631 * Pr_{Arable} \text{\textasciicircum}2 + 0.00759181 * Pr_{Perennial\ pl} - 0.000165105 * Pr_{Perennial\ pl} \text{\textasciicircum}2 \quad (9)$$

Coefficient of determination (R^2) of the multiple regression equation is 0.99, the value that can be considered within reasonable limits. For equation validation, the ratio of elementary specific discharge where *n* was determined by multiple regression equation and the one where *n* was evaluated based on the time series general analysis from 26 hydrological stations, resulted in a R^2 of 0.58 and the average difference between the results is approx. 1.21 $m^3/s/km^2$.

Reservoirs effect

In the genetic model, determination of the effect of reservoir system operation on peak discharge is performed by application of coefficient of peak discharges control under reservoir impact. For its estimation, the weighted share of reservoirs within the river basin was determined using spatial information (reservoirs area, reservoirs basin area) of over 2100 reservoirs situated in the 50 pilot river basins. As a result, it was estimated, that for vast majority of small and medium-sized rivers of the Republic of Moldova, diminishing of pluvial floods peak discharges under the impact of reservoirs is up to 5%. The decrease of this characteristic by 5-10% is specific for rivers Botnishoara (Botna r. b.), Shovatsul Mare (Camenca r. b.), Delia, Musa, Sholtoaia, Lapushna, Calmatsui. The most significant decrease of flood runoff peak discharge, over 10%, is characteristic for the Bratuleanca and Larga rivers (Botna r. b.).

3.6. Estimation of land cover types contribution to flood volume generation

Assessment of the effect of anthropogenic activity in generation of flood volume (W) was performed by application of volumetric method. Model validation was performed based on information from gauging stations. Subsequently, the method was used for calculation of the volumes for the 50 pilot rivers. In order to simplify the interpretation of the results, the volumes generated on the land cover types were converted into shares and compared to the shares of the land cover types *(Pr)* within the river basins (fig. 25). Also, the shares of volumes and *LU* types were correlated (fig. 26-29).

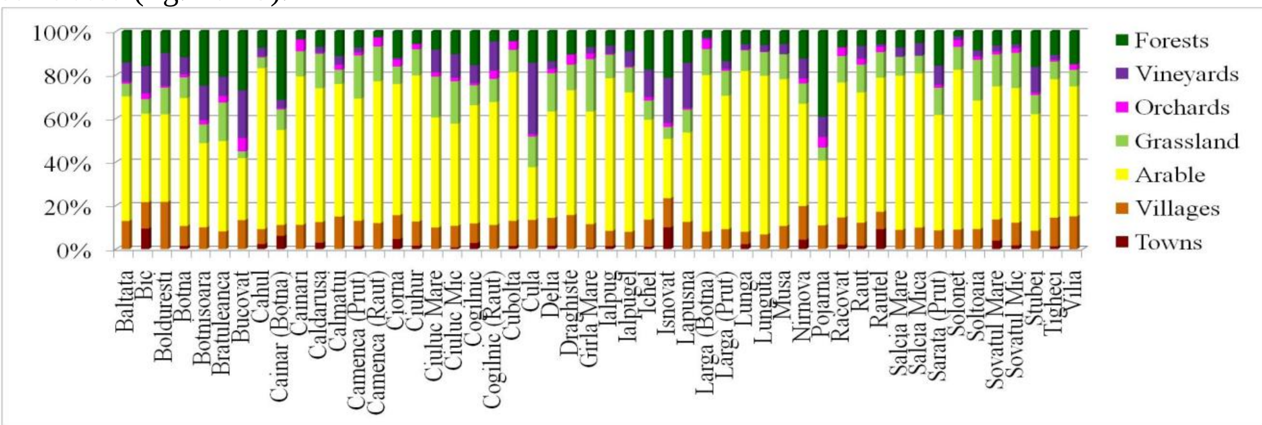

Fig. 25. Share of flood volumes generated on different land cover types, *PP*=100mm

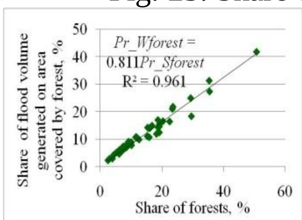

Fig. 26. Relationship between the share of W generated on forest and the share of forest

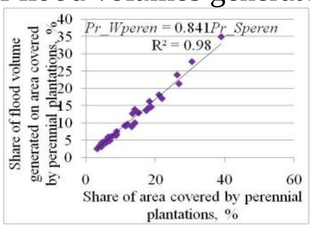

Fig. 27. Relationship between the share of W generated on perennial plantations and the Pr of perennial plantations

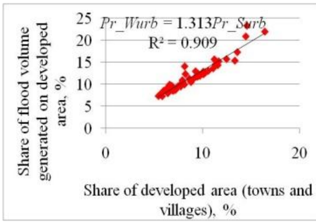

Fig. 28. Relationship between the share of W generated on developed area and the share of towns and villages

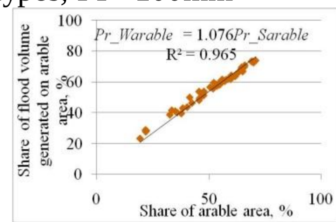

Fig. 29. Relationship between the share of W generated on arable area and the share of arable area

Finally, it was calculated that developed areas as well as forest and grassland influence formation of ~12% each (~35%) of total flood volumes, the biggest part being formed on agricultural land.

4. EVALUATION OF ANTHROPOGENIC IMPACT ON FLOOD RUNOFF GENERATION AND PROPAGATION BASED ON DYNAMIC MODELS

4.1. Modification of pluvial flood generation processes under the impact of land cover change and reservoirs operation

Pilot rivers and specific land cover changes

The modification in the flood wave hydrographs under the impact of land use change for the last 3 decades was performed using the JAMS/J2000 hydrological model [30], on the example of 11 which conventionally represent the northern, central and southern part of the country (the Cainari r. - Sevirova st., the Cubolta r. - Cubolta st., the Raut r. - Baltsi st., the Baltsata r. - Baltsata st., the Byc r. - Strasheni st. and Chisinau st., the Pojarna r. - Sipoteni st., the Isnovats r. - Syngera st., the Botna r. - Causheni st., the Ialpug r. - Comrat st., the Salcia Mare r. - Musait st., the Lunga r. - Cheadyr-Lunga st.). The changes in the land cover for the period 1982-2013 are represented in form of shares in the figures 30, 31.

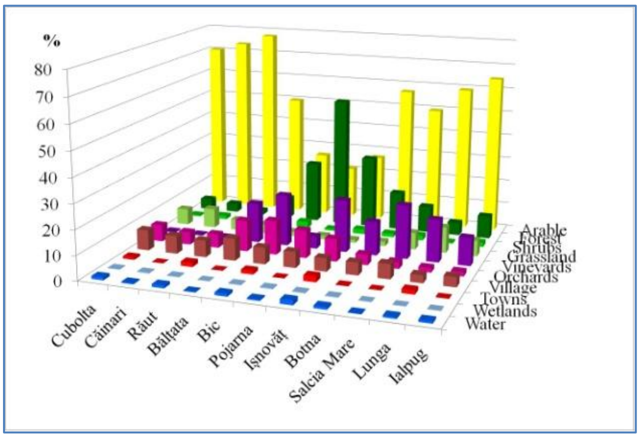

Fig. 30. Land cover types share in the river basins, till hydrological station, 1982

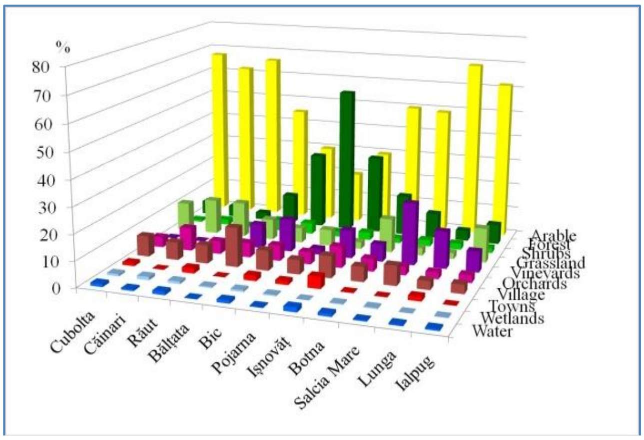

Fig. 31. Land cover types share in the river basins, till hydrological station, 2013

Application of hydrological modeling on pilot rivers

A good representation of the basin conditions within virtual models from JAMS/J2000 requires a good understanding of the processes that occur in river basins, especially, during the period of pluvial floods. Based on the analysis of flood generation factors and identification of values of the variables needed for hydrological modeling, the procedure of construction, calibration and validation of the models for all pilot-river for entire hydrological monitoring period was performed. For evaluation of model quality, the efficiency criteria and the ratings assigned to them were used [39]. The quality of all performed models falls within the allowable limits for both calibration and validation periods.

Evaluation of land cover change impact

Taking into account the fact that the synoptic situations that lead to flood generation have a tendency to repeat and, in recent years, to intensify, it was considered important to evaluate the flood peak and average discharge and flood volume changes for all flood events modeled in the present study using consecutively the spatial data of the land cover types from 1982 and 2013. As at the level of shares, no significant changes in the land use of the 2 periods (fig. 30, 31), are observed, it is assumed that the same tendency is also characteristic for the runoff components.

In order to generalize the modeling results, the average difference for all flood hydrographs of the models simulated using *LU 2013* and the one based on *LU 1982* was calculated. Thus, on the basis of the results analysis, it is observed, in general, an increasing trend of the values of flood runoff characteristics for rivers from the central and southern part of the country and a decreasing one for those of the northern part of the country. In the case of the formation of synoptic situations similar to those that caused the pluvial floods on *rivers in the northern part of the country*, the maximum runoff characteristics under the current *LU* conditions would decrease by 10% in the case of the Raut (fig. 32) and the Cainari rivers compared to the *LU* conditions of 1982, for the Cubolta r. this decrease is of 4%. This fact is explained by the naturalization process of the river basins, in particular, by reducing the share of arable land and the growth of grassland and forest. In the case of the *rivers from the southern part of the country*, the land use change results in a reduction in the flood peak discharge, average discharge and volume formed on the Ialpug r. of about 10% but an increase of about 2-10% in the case of the Lunga and the Salcia Mare rivers. Changing the flood runoff of *the rivers in the central part of the country* differs from one river to another. In the case of the floods on the Pojarna r. there are no major changes. The decrease in the flood peak discharge, average discharge and volume from the Botna river basin are due to the decrease of arable areas and vineyards, and to the increase of those occupied by pasture and shrubs. The increase of flood runoff characteristics of the Baltsata and the Ishnovats rivers is determined by the settlements enlargement, the decrease of the areas occupied by the perennial plantations. Nevertheless, the most significant change in the flood peak discharge, average discharge and volume is attested for the Ishnovats r., this being +35% (fig. 33). Practically double increase of urban and rural settlements, the double decrease of the vineyards are the main causes of this growth.

Estimation of reservoir operation impact

Assessment of reservoirs influence on maximum runoff was performed on the basis of analysis of the Byc r. flood runoff at Chisinau station, modified by the Ghidighici res. operation. For this purpose, the hydrological model for the Byc r. at Chisinau st., located downstream of the reservoir as well as at Strasheni st., situated upstream of it was constructed, calibrated and validated. In order to increase the accuracy of the models, the intercalibration procedure was used to evaluate the variables values of the models of the Byc r., Strasheni st. and Chisinau st., the latter being built for the natural runoff period. Decrease of maximum runoff characteristics by the Ghidighici res. is due to a rather large capacity to accumulate the pluvial floods generated in the upstream of the reservoir. Peak discharge change is significant, it is 3, 5 in some cases, even 15 and 20 times lower than in the case of natural runoff modeling. It should be mentioned that the flood wave transformation till the yearly '90s is characterized by higher outflow discharges, in comparison to this, in the current period there is no noticeable increase of the outflow discharges over 5-6 m^3/s in spite of increasing frequency of maximum precipitation (fig. 34).

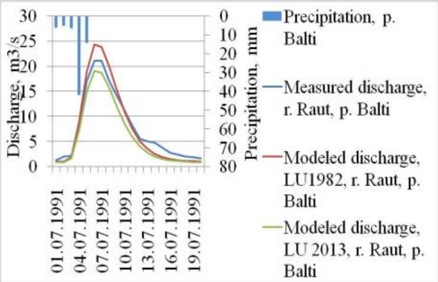

Fig. 32. Measured and modeled pluvial flood hydrographs, Raut r., Baltsi st.

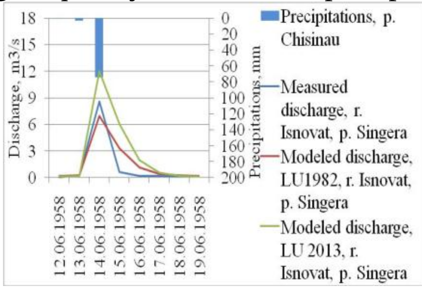

Fig. 33. Measured and modeled pluvial flood hydrographs, Ishnovats r., Syngera st.

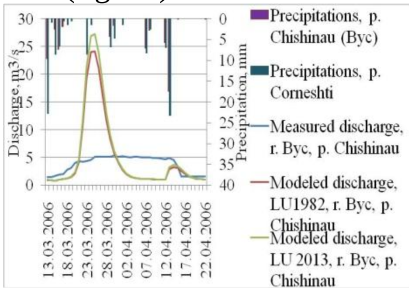

Fig. 34. Measured and modeled pluvial flood hydrographs, 2006, the Byc r., Chisinau st.

4.2. Modification of flood wave propagation processes under the impact of hydrotechnical structures and climate change

Pilot rivers

Evaluation of flood wave dynamics in conditions of river bed changes was performed for two pilot zones: the first being the sector on the Dniester river from Hrushca st. (upstream Dubasari res.) to Talmaza vil. (where the Dniester branches into the Dniester and the Turunchiuc distributary), and the second - the sector on the Byc river from the Ghidighici res. up to its mouth. In the limits of the study area, in the floodplain of the Dniester and Byc rivers there are present flood defense hydrotechnical structures: the Dubasari and Ghidighici reservoirs as well as levees with a length of 424.1 km (194.4 km on the right side and 229.7 km on the left side of the Dniester r.) and 127.2 km that should protect against floods an area of over 38184 ha and 4591 ha, respectively [11].

Application of hydraulic modeling on pilot rivers

The hydrodynamic model used for estimation of changes in flood wave propagation under the impact of reservoirs, levees, climate changes is the HEC-RAS 5.0.3 [28]. For modeling of outflow flood hydrographs from the Dubasari and Ghidighici res. two methods integrated in the model were applied: Elevation Controlled Gates method *M2*, Navigation Dam method *M3*. Assessment of model quality was performed using the same efficiency criteria like in case of hydrological modeling, the result being good and very good (fig. 35, 36).

Evaluation of reservoirs impact on flood wave dynamics

The Dubasari and Ghidighici reservoirs were built in the '60 of the last century for irrigation, recreation, fishery, flood protection etc. The direct impact of the reservoirs and, especially, of the decrease of their volumes due to siltation processes, was performed taking into account the useful and flood storages of the reservoir from the year of construction and from 2000 for assessment of the 10, 5, 1, 0,5 and 0,1%. flood wave propagation scenarios. As a result, it was determined that the Dubasari res. modifies the probable peak discharges with 10-15%, and the Ghidighici res. would decrease the discharges even with 40% (fig. 37, 38). The change in reservoirs volumes would lead to the increase of peak discharge attenuation coefficient. For example, in the case of the Byc r, it would increase from 0,67-0,75 to 0,71-0,78.

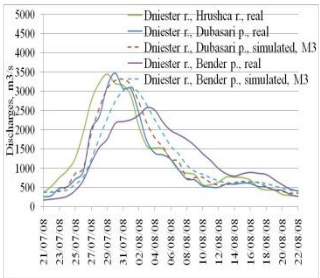

Fig. 35. Measured and modeled flood hydrographs, flood of 2008, the Dniester r.

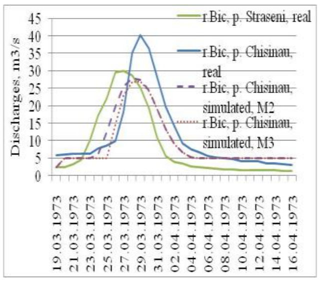

Fig. 36. Measured and modeled flood hydrographs, flood of 1973, the Byc r.

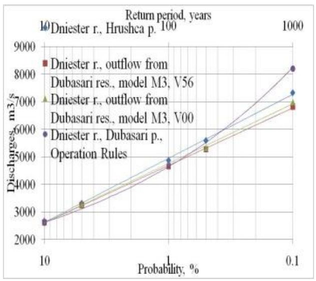

Fig. 37. Probable peak discharge change under the impact of the Dubasari res. siltation

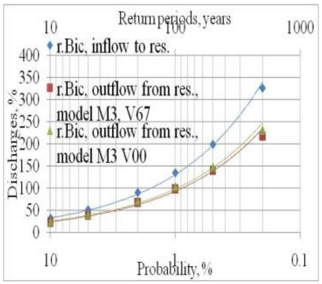

Fig. 38. Probable peak discharge change under the impact of the Ghidighici res. siltation

Estimation of protection levees impact on flood wave propagation

As a result of modeling of the levee impact on flood wave propagation it was estimated that the absence of *these hydrotechnical structure* would increase the flood propagation time by 1-2 days for the Dniester and Byc rivers. The average water level would decrease by 0,5-2,3m for the Dniester r. and 0,2-0,5 m for the Byc r. Average water velocity would diminish by 1,5 time. For the Dniester r., the hazard areas would be of 82-380 km^2 in the case of presence of the defense structures and 293-442 km^2 in case of their absence. Thus, the flood-prone area during 5-10% floods would be 3.5 times smaller in case of levee presence. In case of the Byc r., the hazard area would be 5-30 km^2 in the case of levee presence and of 11,7-34 km^2 if these are absent. The changes in peak discharges and flood hazard/risk areas are represented in the figures 40-49. In case of the Dniester r. the number of people affected by the floods could rise up to 10000-45000 ths. depending on the exceeding probability and protection degree. The share of very severely affected people in case of levees presence is 31-41%, in case of their absence - 20-36%, and of the affected people is would be of 41-53% for the first scenario and - 47-66% for the last one. The potential loss caused by floods would amount to 83-330 mil. Euro in the case of levees presence and to 102-339 mil. Euro in case of their absence. In case of occurrence of floods of 0.1-10% probability and the presence of defense structures the share of damage caused to rural areas would be 26-37%, to urban areas - 31-37% and to industrial zones - 27-35%. In case of levees absence, the damage caused to rural settlements would be 32-38%, to urban ones - 29-30%, to industrial zones - 26-29%. The agricultural areas would be damaged by about 6-13% of the total, the value diminishing with the decrease of the exceedance probability.

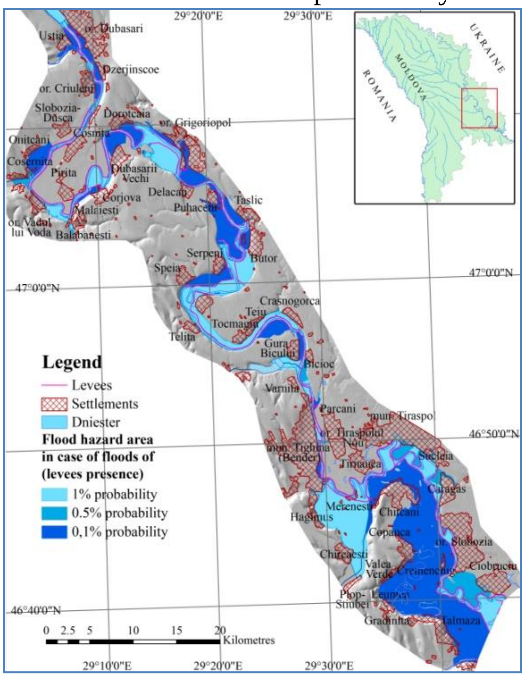

Fig. 40. Flood hazard areas in conditions of levee presence, st. Dubasari p - Talmaza vil. section

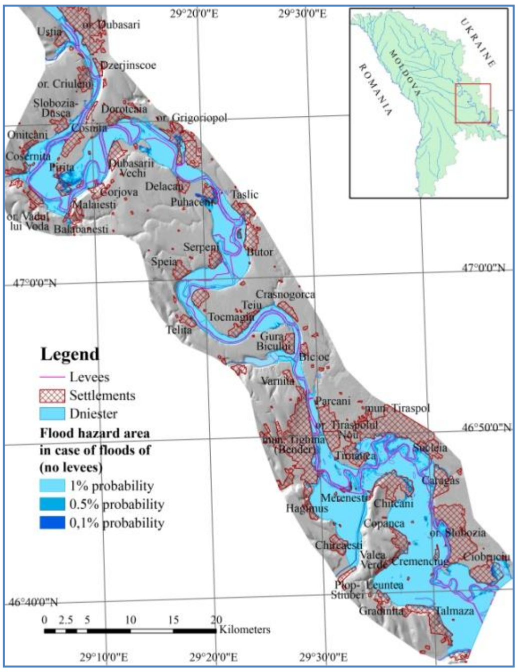

Fig. 41. Flood hazard areas in conditions of levee absence, st. Dubasari p - Talmaza vil. section

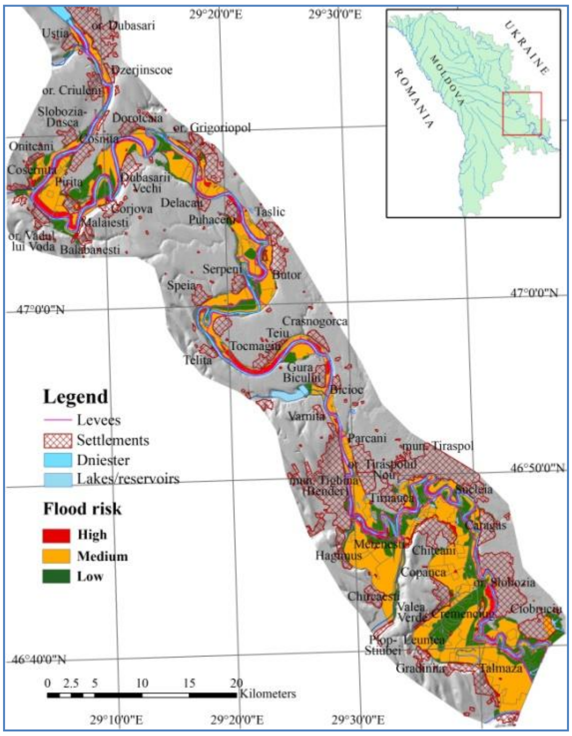

Fig. 4.42. Flood risk areas in conditions of levee absence, st. Dubasari p - Talmaza vil. section

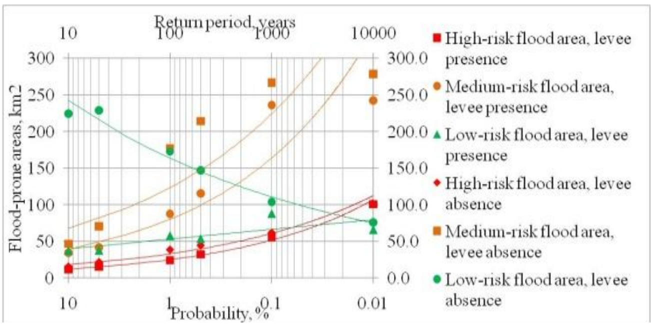

Fig. 43. Flood risk areas changes in conditions of levee absence/absence, the Dniester r. (st. Dubasari p - Talmaza vil. section)

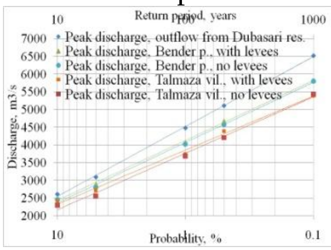

Fig. 44. Probable peak discharges changes under levees impact, the Dniester r.

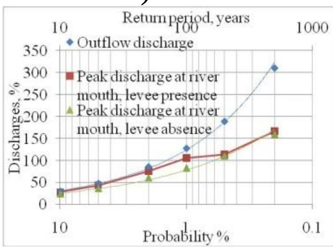

Fig. 45. Probable peak discharges changes under levees impact, the Byc r.

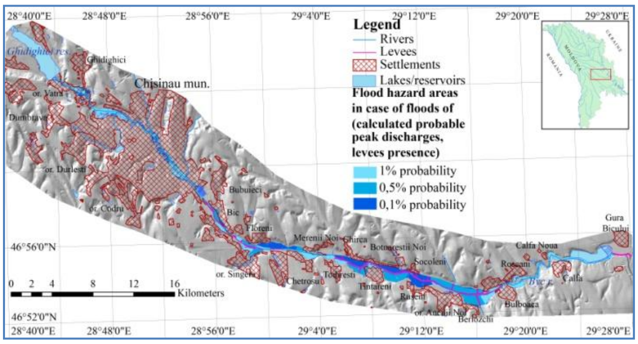

Fig. 46. Flood hazard areas in case of levee presence, calculated probable peak discharges

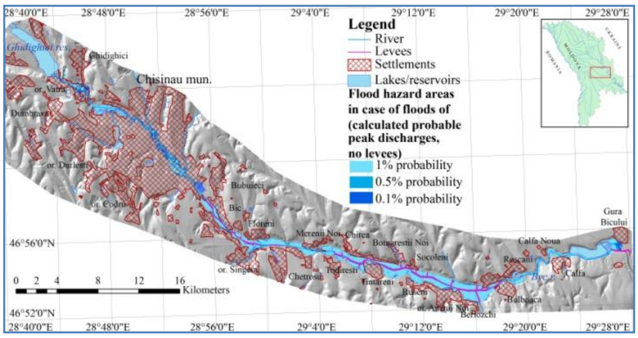

Fig. 47. Flood hazard areas in case of levee absence, calculated probable peak discharges

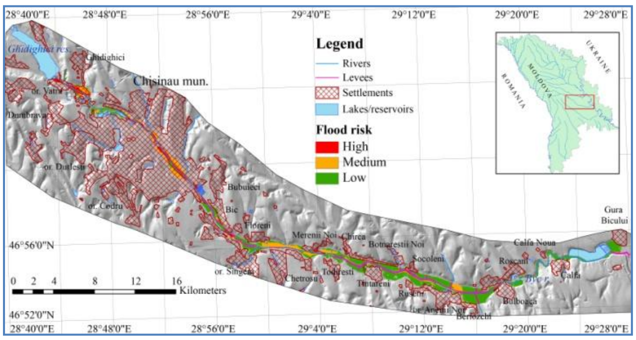

Fig. 48. Flood risk areas in case of levee absence

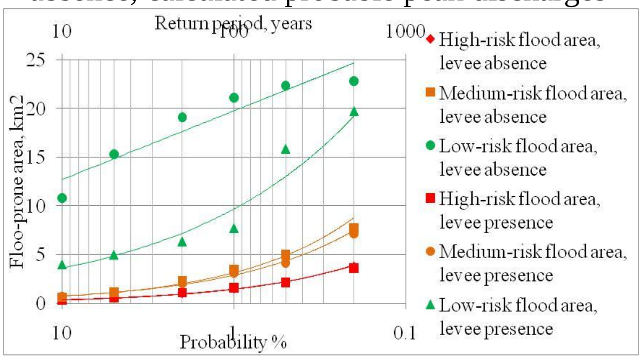

Fig. 49. Flood risk areas changes in conditions of levee absence/absence, the Byc r. (sector downstream of the Ghidighici res. - river mouth)

In the case study area on the Byc r. there are not observed big differences in the number of affected people in conditions of presence and absence of defense structures, fact explained by settlements positions within the floodplain and absence of levees in their vicinity. The number of affected people increases to 5,000 inhabitants, being virtually null in the case of medium floods propagation due to the fact that settlements are not inundated. Most of the people would not be seriously affected by pluvial floods, both in case of levee presence and absence.

The damages estimated for the 5 scenarios are within the limits of 5-95 mil. Euro in case of levee presence and of 7-110 mil. Euro if these are absent. The most affected areas would be the industrial ones, the damage caused to them would exceed 75% of the total damage caused by floods. In particular, industrial zones in the Chisinau municipality would be flooded. The proportion of damage caused to agricultural areas compared to industrial and urban areas would be practically insignificant.

Evaluation of climate change impact on flood risk

The climate change would lead to the increase of flood runoff characteristics by 20% in case of the Dniester r. and by 30% in case of the Byc r. [19]. The peak discharges of 1% would be equal to the actual ones of 0,5-0,6%. The hazard areas would increase by 19-25 km^2 in case of the Dniester and by 3 km^2 in the case of the Byc r. Water level and velocity would not be modified significantly. The change in peak discharge, flood risk area, affected population and potential damage under the impact of climate change are represented in figures 50-57.

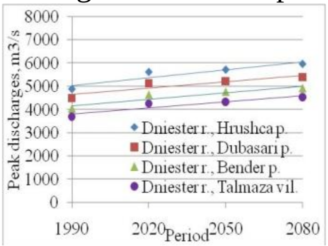

Fig. 50. Modification of 1% peak discharges under climate change impact, the Dniester r.

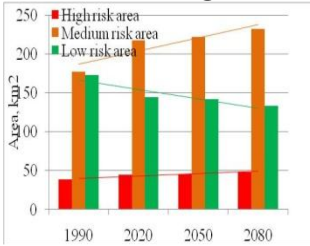

Fig. 51. Modification of flood risk areas in case of 1% flood wave under climate change impact, the Dniester r

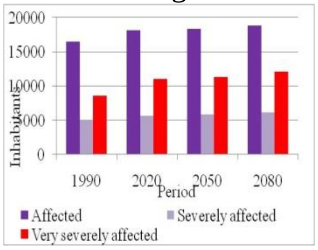

Fig. 52. Modification of people categories affected by 1% pluvial floods under climate change impact, the Dniester r.

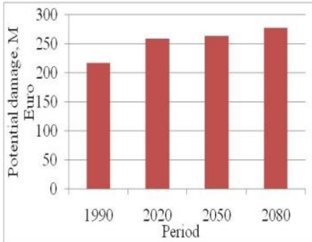

Fig. 53. Modification of potential losses caused by 1% flood wave of the Dniester r. under climate change impact

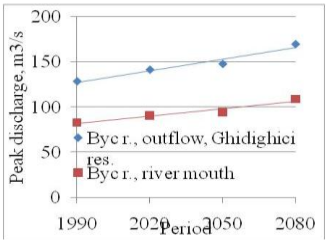

Fig. 54. Modification of 1% peak discharges under climate change impact, the Byc r.

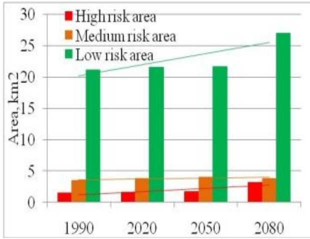

Fig. 55. Modification of flood risk areas in case of 1% flood wave under climate change impact, the Byc r.

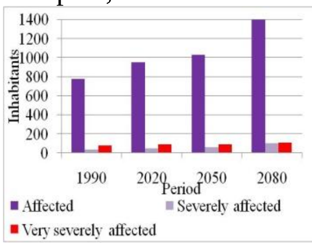

Fig. 56. Modification of people categories affected by 1% pluvial floods under climate change impact, the Byc r.

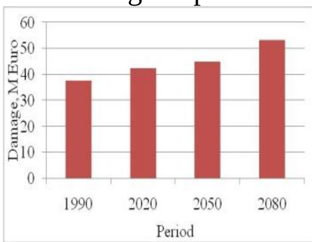

Fig. 57. Modification of potential losses caused by 1% flood wave of the Byc r. under climate change impact

It should be mentioned the from the risk categories, the areas of high risk would increase by 2 times in the case of the Byc r., and in case of the Dniester r. the low flood risk area would decrease in the favor of the high one. The climate changes would cause the increase of the number of affected people, especially, of those severely affected in the case of both rivers. The share of damages classified according to land use types would remain at the level of actual period.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

1. As a result of comparative analysis of flood runoff characteristics in stationary and non-stationary conditions, the coefficient of anthropogenic impact on the flood runoff characteristics was developed. Its applications showed that, in conditions of anthropogenic activity, summer runoff depth can change with 19%, flood runoff depth - with 12%, and peak discharge of pluvial floods - with 4%. However, at the moment, flood runoff for the vast majority of rivers is characterized by quasi-stationary processes [12].
2. The reservoirs caused a slight increase of coefficient of attenuation of peak discharges generated on the Dniester r. from 0.30 to 0.40 (under natural conditions) to 0.50-0.60 (under the conditions of anthropogenic influence) [35]. The same coefficient, in the case of the Prut r., was reduced

from 0.41 to 0.29. The analysis of the probable peak discharges of 0.1-10% calculated based on monitoring data in comparison with those from the reservoirs Operation Rules showed that the first ones are lower than the latter, fact that certifies the possibility to improve the flood control methods.

3. Results of *FFPI, FPI* and the new *FPPI* index modeling showed that ~ 60% of the country's territory and of the studied rivers fall in the class of the average potential for flood wave generation, accumulation and propagation. The regions characterized by high and very high flooding potential (~30% of the territory of the republic) are located in the floodplain of large and medium sized rivers. Also, the high and very high flood wave propagation potential is specific for rivers in the central and southern part of the country (~40% of the 50 studied rivers) [31].
4. For the optimization of the genetic method, the relationship of values of the flood hydrograph shape coefficient and of land use types share within the river basins of the Baltsata water balance station was identified and a new equation for this coefficient calculation for the estimation of the probable peak discharge of ungauged rivers was proposed. The evaluation of the coefficient of peak discharges control under reservoir impact from the same method, performed by estimation of the weighted share of reservoirs within the river basin, showed that their impact is minor (maximum 16%) [13].
5. Regional estimation of flood runoff generated in small basins, where a certain land cover type predominates, has demonstrated that the maximum runoff is 2 times lower in the case of prevalence of natural vegetation compared to the case of developed land. The anthropogenic impact expressed by land use change over the last 3 decades has caused minor changes in flood runoff at the bazinal level (-6.2-4.3mm), but at the local level the increase/decrease of the maximum runoff depth is substantial (-67-57mm). Also, it was estimated that in conditions of soils featuring a high moisture caused by antecedent precipitation or by the irrigation process, the flood runoff values may increase from 30 to 60%. In the case of the compaction of soil due to agricultural tillage, an increase of flood runoff of about 17-38% (depending on soil moisture) was estimated [32].
6. Assessment of the land cover types contribution to flood volumes generation resulted in the fact that settlements as well as forest and pasture influence the formation of 35% (12% each) of the total volume, the vast majority of flood runoff being generated on agricultural land, the share being of 65%. The effect of land cover differs from one basin to another depending on the share of different land cover types [33].
7. For modeling of pluvial flood generation processes by application of J2000 hydrological model the land cover dynamics over the last 30 years was determined and represented in the model. Results of this dynamics impact on pluvial floods show, on the one hand, the decrease of the flood runoff characteristics for the rivers from the northern part of the country, and, on the other hand, the increase of those in the southern part by about 10%. Substantial increase (+35%) of the flood runoff is specific for the Isnovats r.. The decrease of the floods runoff characteristics is caused by the processes of naturalization of agricultural land, while the increase is determined by the expansion of the urbanized areas [34].
8. Simulation of the impacts of levees system on the dynamics of the flood wave of the Dniester and the Byc rivers using HEC-RAS model shows that the floods protection is effective in case of high and medium probability floods. The narrowing of the flood wave propagation area by levees causes higher peak discharges, water depth and velocity and lower flood wave duration and flood risk areas. The levee absence can cause flooding of area that, in the case of high and medium probability floods, can be even 3 times larger than in case of presence of defense structures.
9. In the last decades, there is registered the occurrence of pluvial floods in non-specific months for these phenomena (spring/autumn), but also the shift of maximum number of pluvial floods from June to July for the rivers from the northern part of the country is registered. This fact is explained by the increase in the degree of instability of climatic processes favoring the

generation of pluviometric excesses. Towards the end of the 21st century, due to the climate change, the probable peak discharges of flood runoff from the Dniester and Byc rivers will increase by 22-32% [19], thus determining flooding of larger areas that can cause potential damages of over 230 mil. Euros and affect a total number of 37000 inhabitants from the floodplains of these two pilot-rivers.

Recommendations:

1. For the study of the pluvial floods of the rivers of the Republic of Moldova, for the first time, new methods/models for calculation/simulation of the maximum runoff characteristics were used: FFPI, FPI, FPPI, volumetric, SCS-CN, JAMS/J2000, HEC-RAS, Indicators of Hydrological Alterations and Environmental Flow Components approaches as well as the methods already existed and applied at national level in the field of hydrotechnical design were improved. The listed models were successfully calibrated, validated and applied and are recommended for further utilization for hydrological research and for highlighting the impact of changes in the environment produced/planned by anthropogenic activity on the processes of generations and propagation of pluvial floods.
2. As a result of performed studies, a large set of cartographic materials of flood runoff characteristics was developed. These maps are recommended for completing national normative documents and can be used to calculate the maximum runoff characteristics of ungauged rivers as well as to design different hydrotechnical structures but also to develop terrain planning and flood management plans at district, bazinal, national level. The obtained results are recommended to be utilized for development of river basin management plans and for the elaboration of programme of measures in order to improve the ecological status/potential of the water bodies.
3. The dynamic models used in the research are recommended for application in the process of hydrological forecasts development and for estimation of flood hazard/risk areas, of damages and affected people as well as of temporal evolution of flood runoff characteristics. These can be used also for simulation of real/modeled floods propagation as well as for estimation of the impact of possible changes within the complex of structural and nonstructural flood control measures. The research results can also serve as an argument for extension of the hydrological and meteorological monitoring network based on the bazinal principles for a more effective hydrological forecasts, especially, of flash floods as well as for development of new dynamic models for small, medium and large transboundary rivers. In conditions of reservoirs operation, it is recommended to develop new river runoff control regulations based on estimation of Environmental Flow Components for the years of high, average and low moisture conditions.

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2. **Jeleapov A.** *Assessment of regional variation of flood runoff in the Republic of Moldova*. Present Environment and Sustainable Development, vol. 12, no. 1, 2018, p. 35-47. DOI 10.2478/pesd-2018-0003, http://pesd.ro/articole/nr.12/nr.1/10432%20-Volume12_issue_1%_2003_paper.pdf. (accessed 10.04.2018).
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c. 164-167. ISBN 978-9975-66-219-2, http://eco-tiras.org/books/berg_135let.pdf. (accessed 10.04.2018).

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22. **Jeleapov A.,** Fink M., Sven K. 2018 *Assessment of anthropogenic impact on flood dynamics in Moldova using hydrological modeling* https://fallmeeting.agu.org/2018/abstract/ assessment-of-anthropogenic-impact-on-flood-dynamics-in-moldova-using-hydrological-modeling/ (accessed 10.02.2019).

International conferences in the republic

23. **Chişciuc (Jeleapov) A**. *Analiza temporală a viiturilor pluviale pe rîurile Republicii Moldova*, International Conference of Young Researchers: book of abstracts, VIII editions, Chisinau, 2010, p. 71. ISBN 978-9975-9898-4-8 www.pro-science.asm.md/conf/conf_2010.pdf. (accessed 10.04.2018).

ADNOTARE

Jeleapov Ana „Evaluarea impactului antropic asupra viiturilor pluviale de pe râurile Republicii Moldova”. Teza de doctor în științe geonomice, Chișinău, 2019.

Teza constă din introducere, patru capitole, concluzii generale și recomandări, 264 surse bibliografice, 150 pagini de text de bază, 165 figuri, 17 tabele, 191 anexe. Rezultatele obținute sunt publicate în 23 lucrări științifice.

Cuvinte cheie: viituri pluviale, modelare hidrologică și hidraulică, impact antropic, acoperirea terenului, lacuri de acumulare, SIG.

Domeniul de studiu: geografie, hidrologie.

Scopul studiului: evaluarea modificărilor caracteristicilor viiturilor pluviale în condițiile impactului antropic .

Obiectivele cercetării: identificarea și aprecierea modificărilor regimului scurgerii de viitură sub acțiunea activității antropice în baza metodelor statice; simularea impactului antropic asupra proceselor de formare și propagare a undelor de viitură de pe râurile pilot, utilizând modele hidrologice și hidrodinamice; aprecierea modificărilor zonelor riscului la inundații în condițiile schimbărilor de mediu.

Metodologia cercetării științifice. Pentru realizarea scopului și obiectivelor studiului au fost utilizate următoarele metode: metoda comparativă, Indicatorii Modificărilor Hidrologice, Componentele Scurgerii de Mediu, metoda genetică, metoda volumetrică, metoda Numărul de Curbă (SCS-CN), modelul hidrologic JAMS/J2000, modelul hidrodinamic HEC-RAS. De asemenea, în lucrare se aplică analiza factorială, SIG și metode statistice.

Noutatea și originalitatea științifică. Pentru prima dată pentru teritoriul Republicii Moldova au fost estimate caracteristicile scurgerii de viitură în condiții staționare și nestaționare, precum și a fost determinată dinamica temporală a viiturilor pluviale sub acțiunea modificărilor în acoperirea terenului și funcționării lacurilor de acumulare. A fost apreciat și cartografiat potențialul de formare, acumulare și propagare a viiturilor pluviale pentru teritoriul țării. Utilizând metoda Numărul de Curbă, metoda volumetrică și modelul hidrologic fizic distributiv JAMS/J2000 a fost demonstrat impactul utilizării terenului și activității agricole asupra caracteristicilor viiturilor pluviale. În baza utilizării SIG și modelului HEC-RAS a fost estimat impactul schimbărilor climatice și a construcțiilor hidrotehnice: lacurilor de acumulare și a digurilor de protecție asupra propagării undei de viitură prin albie și luncă și a distribuției spațiale a riscului la inundații.

Problema științifică importantă soluționată constă în evaluarea modificărilor caracteristicilor temporale și spațiale ale scurgerii de viitură de pe râurile Republicii Moldova determinate de activitatea antropică.

Semnificația teoretică. Au fost identificați și analizați comparativ Indicatorii Modificărilor Hidrologice și Componentele Scurgerii de Mediu și evaluat impactul utilizării terenului și a lacurilor de acumulare asupra caracteristicilor scurgerii de viitură. A fost modelată repartiția spațială a indicilor potențialului viiturilor rapide, inundării și propagării undei de viitură pe teritoriul Republicii Moldova. A fost estimat aportul categoriilor acoperirii terenurilor și activităților agricole în formarea viiturilor pluviale și apreciate modificările proceselor de formare și propagare a undei de viitură sub acțiunea construcțiilor hidrotehnice, schimbărilor climatice și managementului terenurilor.

Valoarea aplicativă a lucrării. Rezultatele obținute pot fi utilizate pentru elaborarea planurilor de amenajare a teritoriului în vederea diminuării scurgerii maxime, optimizarea managementului viiturilor pluviale, implementarea măsurilor structurale și nonstructurale de protecție contra inundațiilor. De asemenea, rezultatele pot servi drept bază metodologică pentru perfecționarea documentelor normativelor naționale pentru determinarea caracteristicilor hidrologice de calcul.

Implementarea rezultatelor științifice. Hărțile digitale privind scurgerea de viitură au fost implementate de Consiliile Raionale Glodeni și Fălești pentru elaborarea planurilor de amenajare a teritoriului și gestionarea bazinului hidrografic Camenca. Unele rezultate obținute au fost utilizate pentru managementul durabil al resurselor de apă și a situațiilor de risc hidrologic, optimizarea funcționării lacurilor de acumulare de către Direcția bazinieră de Gospodărire a Apelor, Agenția ”Apele Moldovei”.

ANNOTATION

Jeleapov Ana „Assessment of the anthropogenic impact on pluvial floods of the rivers of the Republic of Moldova". PhD thesis in Geonomic sciences, Chisinau, 2019.

The thesis consists of introduction, 4 chapters, general conclusions and recommendations, 264 references, 150 pages of basic text, 165 figures, 17 tables, 191 annexes. The obtained results are published in 23 scientific papers.

Key words: pluvial floods, hydrological and hydraulic modeling, anthropogenic impact, land cover, reservoirs, GIS.

Field of study: geography, hydrology

Study aim: assessment of changes in pluvial floods characteristics in conditions of anthropogenic impact.

Research objectives: identification and estimation of changes in pluvial flood runoff regime under the influence of anthropogenic activity on the basis of static methods; modeling of anthropogenic impact on flood waves generation and propagation processes of the pilot rivers using hydrological and hydrodynamic models; assessment of flood risk changes in conditions of environmental modifications.

Research methodology. The following methods were used to achieve the purpose and objectives of the study: comparative method, Indicators of Hydrological Alterations, Environmental Flow Components approaches, genetic method, volumetric method, Curve Number method (SCS-CN), JAMS/J2000 hydrological model, HEC-RAS hydrodynamic model. Factorial analysis, GIS, and statistical methods were also applied in the research.

Scientific innovation and originality of the work: For the first time for the territory of the Republic of Moldova, flood runoff characteristics under stationary and non-stationary conditions were estimated and temporal dynamics of pluvial floods under the influence of land cover changes and reservoirs operations were determined. Flash floods, flooding and flood wave propagation potential was calculated and mapped. Using SCS-CN method, volumetric method and JAMS/J2000 physically-based fully distributed hydrologic model the impact of land use and agricultural activity on flood runoff characteristics was demonstrated. Using GIS and HEC-RAS model, the impact of climate change and hydro-technical constructions: reservoirs and levees on flood wave propagation through the river bed and floodplain and the spatial distribution of flood risk was estimated.

The important scientific problem solved consists of assessment of changes in temporal and spatial characteristics of flood runoff on the rivers of the Republic of Moldova caused by the anthropogenic activity.

Theoretical significance. Indicators of Hydrological Alterations and Environmental Flow Components were identified and comparatively analyzed and land use and reservoirs impact on flood runoff characteristics was assessed. Spatial distribution of the indexes of flash floods, flooding and flood wave propagation potential on the territory of the Republic of Moldova was modeled. The contribution of land cover types and agricultural activities in pluvial flood generation was estimated and modifications of flood wave generation and propagation processes under the action of hydrotechnical structures, climate change and land management were evaluated.

Applicative value of the research. Obtained results can be used for development of territorial planning activities for mitigation of maximum runoff, optimization of pluvial floods management, implementation of structural and nonstructural flood protection measures. Furthermore, the results can serve as methodological basis for improvement of national normative documents for determination of computed hydrological characteristics.

Implementation of scientific results. Digital maps on pluvial flood runoff were implemented by the Districts Councils of Glodeni and Faleshti for the development of the urban and territorial planning and management of the Camenca river basin. The obtained results were used for the sustainable management of water resources and hydrological risk situations, reservoirs operation optimization by the Basin Water Management Authority, "Apele Moldovei" Agency.

АННОТАЦИЯ

Желяпов Анна «Оценка антропогенного влияния на сток дождевых паводков рек Республики Молдова». Диссертация на соискание ученой степени доктора геономических наук, Кишинев, 2019.

Диссертация состоит из вступления, 4 глав, общих заключений и рекомендаций, 264 библиографических источников, 150 страниц основного текста, 165 рисунок, 17 таблиц, 191 приложений. Полученные результаты опубликованы в 23 научных работах.

Ключевые слова: дождевые паводки, гидрологическое и гидравлическое моделирование, антропогенное влияние, ландшафтный покров, водохранилища, ГИС.

Область исследований: география, гидрология

Цель исследования: оценка изменений характеристик дождевых паводков в условиях антропогенного влияния

Задачи исследования: выявление и определение изменений режима стока дождевых паводков под воздействием антропогенной деятельность на основе статических методов; моделирование антропогенного влияния на процессы формирования и распространения паводочных волн на пилотных реках используя гидрологические и гидродинамические модели; оценка изменений зон риска наводнений в условиях преобразования окружающей среды.

Методология научных исследований. Для реализаций задачи и целей исследования были использованы следующие методы: сравнительный метод, подходы Показатели Гидрологических Изменений, Компоненты Стока Окружающей Среды, генетический метод, объемный метод, метод Число Кривой (SCS-CN), гидрологическая модель JAMS/J2000, гидравлическая модель HEC-RAS. Факторный анализ, ГИС и статистические методы также применяются в работе.

Научная новизна и оригинальность: Впервые для территории Республики Молдова, были оценены характеристики стока дождевых паводков в стационарных и нестационарных условиях, а также была определена временная динамика дождевых паводков под влиянием изменений ландшафтного покрова и функционирования водохранилищ. Потенциал формирования ливневых паводков, затопляемости и распространения паводочных волн для всей территории страны был оценен и картографирован. Используя метод Число Кривой (SCS-CN), объемный метод и гидрографическую модель с физическими распределенными параметрами JAMS/J2000 было доказано влияние землепользования и сельскохозяйственной деятельности на характеристики стока дождевых паводков. На основе ГИС и модели HEC-RAS было оценено влияние изменения климата и гидротехнических сооружений: водохранилищ и защитных дамб на распространение паводковых волн через русло- пойменную систему и пространственное распределение риска наводнений.

Разрешенная важная научная проблема заключается в оценке изменений временных и пространственных характеристик стока дождевых паводков рек Республики Молдова обусловленных антропогенной деятельностью.

Теоретическая значимость. Были выявлены и проведен сравнительный анализ Показателей Гидрологических Изменений и Компонентов Стока Окружающей Среды и оценено влияние использования земель и водохранилищ на характеристики паводочного стока. Было смоделировано пространственное распределение показателей потенциала ливневых паводков, затопляемости и распространения паводочных волн на территории Республики Молдова. Была оценена роль категорий ландшафтного покрова и сельскохозяйственной деятельности в формировании дождевых паводков и определены изменения процессов формирования и распространения паводочных волн под воздействием гидротехнических сооружении, изменения климата и управления земельными ресурсами.

Прикладная ценность работы. Полученные результаты могут быть использованы для разработки проектов территориального планирования с целью снижения максимального стока, оптимизации управления дождевыми паводками, внедрения структурных и неструктурных мер защиты от наводнений. А также, результаты можно применить в качестве методологической основы для совершенствования национальных нормативных документов для определения расчетных гидрологических характеристик.

Внедрение научных результатов. Электронные карты паводочного стока были внедрены Районными Советами Глодень и Фалешты для разработки планов землеустройства и управления бассейном реки Каменка. Полученные результаты были использованы Бассейновым Правлением по Управлению Водными Ресурсами, Агентством ”Апеле Молдовей” для устойчивого менеджмента водными ресурсами и гидрологическими опасными явлениями, и для оптимизация функционирования водохранилищ.

JELEAPOV ANA

ASSESSMENT OF THE ANTHROPOGENIC IMPACT ON THE PLUVIAL FLOODS OF THE RIVERS OF THE REPUBLIC OF MOLDOVA

166.02 ENVIRONMENT PROTECTION AND RATIONAL USE OF NATURAL RESOURCES

Abstract of doctoral thesis in geonomical sciences

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