Annex No. 4

REVIEW

OF DOCTORAL DISERTATION "DEVELOPMENT OF METHODOLOGY FOR DETERMINATION OF PROTECTION ZONES AROUND WATER RESERVOIRS FROM ASPECT OF SOIL EROSION AND SEDIMENT TRANSPORT" BY MINČEV IVAN, SUBMITED ON THE FORESTRY FACULTY IN SKOPJE

The teaching-scientific board of the Forestry faculty – Skopje, on the meeting which took place on the 9.2.2015, assembled a committee for review of the doctoral dissertation of the candidate MSc Minčev Ivan: "Development of methodology for determination of protection zones around water reservoirs from aspect of soil erosion and sediment transport", consisted of five members: prof. d-r Aleksandar Trendafilov (chair), prof. d-r Ivan Blinkov (mentor), prof. d-r Stanimir Kostadinov, prof. d-r Cvetanka Popovska and prof. d-r Nikolčo Velkovski.

The committee reviewed the doctoral dissertation and submitted to the teaching-scientific board this

R E P O R T

ANALYSIS OF THE THESIS

The doctoral dissertation of the candidate MSc Minčev Ivan: "Development of methodology for determination of protection zones around water reservoirs from aspect of soil erosion and sediment transport", it is consisted of 142 pages font Calibri, size 12, with 1,5 spacing and it has 55 citations of: scientific papers, articles, books, national and international bylaws and internet resources. Beside this, an extensive geo-database is created for the area of interest as well as geospatial models.

The subject of this thesis is very complex and multidisciplinary and requires employing different methodological principals and approaches of the research of the different scientific questions.

The thesis is consisted of seven chapters, plus the introduction, aims and objectives and conclusions. The different parts are structured in sections and subsections and headings and subheadings, which ensures appropriate understanding and following the subject at hand.

In the **Introduction,** the general picture of the field of research is covered and the theoretical frame is given. First some general information about the problem are given (water, reservoirs, erosion, adverse effects of erosion and modeling of processes) and further on the discussion is focused on the specific description of the problem. This chapter gives answers to the basic questions. What is the main subject of the research? Why this question is important? What was known about this subject before this research? How the main investigations will be carried out? How is this thesis going to extend our knowledge?

In the **second chapter** are described the aims and objectives of the thesis. There are six objectives which are described in the following chapters.

In the **third chapter** the region where the research was done and also the used dataset is described. It is given a general description of the geospatial characteristics of the area of interest, as well as the results of the developed geospatial database of the factors who are used in the modeling processes in the following chapters.

The fourth chapter deals with land use in the catchment. The main objective of this chapter is to investigate the dynamics of change in land use for the whole period of existence of reservoirs that are investigated. In the analysis are used combined methods: historical method (for data collection for the land use), induction method (for systematization and analyzing data from various sources, for the choice of method for defining the potential of erosion) etc. The entire database is transferred in GIS environment. The main factors that are subject of research in this chapter are: demographics in the region, arable land, pastures, livestock number and forests. Detailed analysis is made of the forest practices in the basin, whereupon are analyzed and the forest management plans, especially the areas critical to soil erosion.

In the period from 1976 to 2011, there is a significant reduction of the agricultural areas, and as a consequence of these processes, the area under forests and pastures are increased. This trend can be observed in the livestock as well, where there is a decrease in livestock. In analyzing forest management plans it is determined that the application of clean cut in both analyzed periods is significantly represented. The results indicate that in the first period they are present with 45.8% of the total cuts and in the second period 61.7%. If we take into account the fact that the ground around the reservoir is mostly mountainous with large slopes, it can be said that this type of logging has a significant impact on increasing the amount of sediment in the reservoir. Given that forests in the basin of the reservoir are largely degraded, primarily due to intense use in the past, unfavorable environmental conditions and strong anthropozoogenic influences, it is necessary in the future to take measures tending to improve the quality and structure of forests, as and contemporary regenerative measures that will ensure quality natural regeneration of the forest without harmful effects on the forest undergrowth and the forest ecosystem in whole.

The **fifth chapter** deals with issues concerning the amount of deposited sediment in reservoirs, as well as the dynamics of sedimentation of the reservoirs over time. The amount and rate of sediment is need for validation of modeling the erosion empirical methods. The measurement of sediment deposited in reservoirs "Kalimanci" and "Gradche" is performed using echosounder with combination of "profile measurements " and "contour measurements". Then the whole database is transferred into GIS environment, and using various mathematical methods, the amounts of sediment are calculated.

The results of the echosounding measurements of the two reservoirs, show a similar trend, i.e. there is a significant difference in the intensity of filling the reservoir between the periods 1969-1985 and 1985-2013. Trends and causes of this phenomenon may be different, so additional analyzes are performed. In the period 1969-1985 the average annual sedimentation of

the reservoir "Kalimanci" is 467.686 m^3/year, and in the period 1985-2013, the average annual sedimentation of the reservoir is 214.325 m^3/year. In the first period, the filling of the reservoir is more than double then the second period.

In the period 1959-1984 the average annual sedimentation of the reservoir "Gradche" is 15.200 m^3/year and for the period from 1984 to 2013 it is 6.031 m3 / year or in the first period, the sedimentation is 2.5 times larger than the second period.

The impact of the man in the first period is much stronger. Livestock and agricultural fund were much more developed, and thus the generation of erosive sediment material much stronger. Further climatic characteristics vary. In the first period is recorded more rainfall which coincides with the reduced air temperatures in comparison with the second period, where rainfall decreases and temperature of the air increases. The second period was characterized by a significant improvement of natural conditions of the catchment. Migration processes led to the abandonment of agriculture land, and part of the agricultural land became re-vegetated to pasture or forest. These changes have improved the situation in the catchment areas, but cannot fully explain the situation of the erosive sediment in reservoirs. For a full explanation of the erosive sediment, also the process of consolidation of the sediment should be introduced. According to some studies, the consolidation of sediment in reservoirs, can greatly affect the final calculation of the sediment, because consolidation may take up to 50 years.

The sixth chapter is devoted to the calculation of the production of erosive material and the transported and deposited erosive sediment. The method of S. Gavrilovic is applied, and its reliability has been validated with measurements of the deposited erosive sediment in the reservoirs. Critical catchments in terms of erosion were delineated, but also the origin of the erosion sediment was investigated. This chapter is a base for the proposed zoning of catchment areas of the reservoirs.

The modern GIS approach applied for the methodology of S. Gavrilovic significantly differs from the classic approach with field prospection and direct mapping of erosion processes and intensity of erosion. Therefore, the modern approach was modified to comply with existing spatial databases. The catchment of the reservoir "Kalimanci" was delineated in sub-catchments (r. Bregalnica, r. Kamenica, r. Dulica, r. Ribnica etc.) and all further calculations were made at that level. Unlike reservoir "Kalimanci", the calculations for reservoir "Gradche" were performed at the level of a single catchment. As input parameters for the methodology of Gavrilovic were used standard databases which are available to the wider professional community in order to enable repeatability and comparability: soil map of RM, erosion map of RM, vector databases of topographic maps of RM 1: 25.000 LPIS and 1: 5,000, DEM 5m, isotherm, izohietic map of Republic of Macedonia, etc. Spatial data were directly reclassified without intervention, except the land use map.

The definition of the "Xa" parameter is typically done using a land cover/use map Corine Land Cover with scale 1: 100,000. The downsides of this database are: small scale that affects the size of the smallest polygon data and classification which is generalized and is

insufficient for purposes of modeling erosion. Because of inaccuracies, this parameter is obtained by combining the two databases: a topographic map and LPIS who were appropriately reclassified according to the recommended values on the methodology of S. Gavrilovic. After detailed prospection of individual classes of land cover, the most problematic category was forest, because it is a general classification of land cover. This class was problematic because when allocating the forest polygons, the type forest type was not specified. So in this class there are forest with cover of 100%, and also discontinuous forests with tree cover from 1 to 5%. Therefore, all these polygons using the procedure of photo-interpretation were assigned values depending on the forest cover and visibility of bare soil. Furthermore, the land cover reclassified map was combined with a map of implemented anti-erosive measures: check dams, applied agro-ameliorative measures, forest reclamation and other measures and activities.

Calculations of the erosion coefficient "Z" were made by applying the previously calculated input coefficients at the sub-catchment area. The values of the level of the catchment reservoir "Kalimanci" are ranging from 0.13 to 0.69 or 0.36 average. For the flow of the river Bregalnica "Z" is 0.33. This indicates that the flow of the river. Bregalnica is less erosive than the immediate tributaries of the reservoir "Kalimanci" (average "Z" = 0.44). The coefficient of erosion "Z" in the basin of the reservoir "Gradche" is "Z" = 0.20. This value is much smaller than the one of the reservoir "Kalimanci".

To determine the critical catchments from aspect of erosion and sediment transport, the calculations for the parameters W, G, Wsp and Gsp are made at sub-catchment level. The specific production of erosive material on sub-catchment level "Wsp" ranges from 102 to 1,064 m^3/km^2/year or average 486 m^3/km^2/year. Total level of accumulation basin "Kalimanci" production of erosive material (W) is 496,780 m3 / year. The specific amount of transported (transferred) erosive sediment on sub-catchment level "Gsp" vary from 642 m^3/km^2/year or average 195 m^3/km^2/year. The average annual amount of re-transported sediment or how much of the transported erosive sediment on average annually is deposited into the reservoir "Kalimanci" is derived as the sum of the average annual amount of transported sediment of all tributaries and the immediate catchment of the reservoir "Kalimanci". This means that the river Bregalnica is considered as one catchment. The specific amount of erosive sediment transported to profile dam "Kalimanci" is 277,393 m^3/year. All direct tributaries of the reservoir "Kalimanci" are transporting / depositing 98,755 m^3/year or 35% of the total deposited sediment is in the reservoir. The remaining 65% of the sediment are coming from the river Bregalnica or 161,860 m^3/year. It is estimated that 53% of the sediment is coming to the measuring profile Ochipale or 146,404 m^3/year or the sub-catchments from profile Ochipale to profile dam are transporting 47% of the total sediment or 130,989 m^3/year. On the other hand, the reservoir "Gradche", the production of erosive material (W) is 17,149 m^3/year or specific "Wsp" 194 m^3/km^2/year. The specific amount of erosive sediment transported to reservoir "Gradche" "Gsp" is 147 m^3/km^2/year or the average annual amount of transported erosive sediment to profile dam "Gradche" is 13.037 m^3/year.

For the period 1985-2013 year, on average in the reservoir "Kalimanci" were accumulated 214,325 m^3/year which is quite close to the value obtained with the methodology of

S. Gavrilovic, 277,393 m^3/year, given that the value obtained from echosunding measurements includes the consolidation of the sediment, and the modeled value shows the sediment in normal state. For the period 1984-2013 the annual average depositing by the methodology of S. Gavrilovic is 13.037 m^3/year. According echosunding measurements, the average annual amount of deposited sediment is 6,125 m^3/year. The data obtained with the methodology of Gavrilovic and echosunding measurements show greater discrepancy, but the trend is present.

The data obtained by echosunding measurements validate the methodology of S. Gavrilovic for both of the reservoirs. The values obtained for all catchments and the total for the entire basins can be taken as reliable number for further modeling of the erosion processes and sediment management. The obtained values for specific amounts of sediment transported to designated catchment are further divided into four categories of criticality. The most extreme values occur in the sub-catchments around the reservoir "Kalimanci" and in the central part of the catchment, above 300 m^3/km^2/year. The lower categories are present around the city Delchevo as in the central-eastern part of the catchment. These categories further will be used in the following sections for zoning the catchment of the reservoir "Kalimanci" in terms of erosion.

The seventh chapter is focused on the catchment of the reservoir "Kalimanci" and the transportation of erosive sediment in the main river Bregalnica. The main objective of this chapter is to model the deposition of erosion sediment in the main river, in order to define areas of deposition and what percentage of the total sediment remains in the catchment, and how much of the total sediment is deposited in the reservoir "Kalimanci". Modelling the transport of erosive sediment is done in HEC-RAS software with GIS support. The deposition zones are then delineate. The main areas of deposition of the sediment are found in the major geomorphological extensions, i.e. fields: Machevo - Mitrašinci, Razlovci and Trabotiviste - Delčevo. Almost 75% of the total sediment in the river Bregalnica is deposited in the geomorphologic extensions.

According to the calculations in HEC-RAS, annually in the reservoir "Kalimanci" are deposited 152,231 m^3 of sediment. This amount is very close to the amount calculated with the methodology of S. Gavrilovic (161,860 m3).

From the analysis made by the two applied models (model S. Gavrilovic and model HEC-RAS) it can be concluded that the calculated values of the transport characteristics of the riverbed are very close and can therefore can be concluded that the model HEC-RAS is compatible with the model of S. Gavrilovic and the data obtained from this model are reliable.

The eighth chapter is dedicated to making assumptions about the vulnerability to changes of the catchment. These assumptions are supported by employing multiple scenarios. There are two approaches for modeling: global and local approach. Within the global approach there are two scenarios: positive and negative scenario. The first scenario is guided by the assumption: what will be the situation with the amount of accumulated annual erosive sediment material in the reservoir if bio-ameliorative works are done in the catchment. The negative scenario is guided by the assumption if the land use is brought in condition before the

construction of the reservoir "Kalimanci". The local approach on the other hand deals with the question: what will happen in the catchment, if cuts are done in the catchment, with different intensity and distance from the reservoir.

From the first scenario it can be concluded that the catchments of rivers Kamenica and Sushica are most critical in terms of erosion, because despite the envisaged measures for improvement, the category of threat does not changes. This means that in the future these two catchments should be given special attention and measures to manage catchment and land should be focused exclusively on the conservation and protection of land.

In the second scenario the situation is very different from the current situation. If the state would return like it was in the 1980's, more than 80% of the catchment would become critical with production more than 301 m^3/km^2/year.

From the global approach scenarios can be concluded that the change of the coefficient "Xa", i.e. the change of land use and application of bio-ameliorative measures throughout the catchment, the situation in the catchment can be improved and it would have impact on the transport of erosive sediment to reservoir. On the other hand, if the pressure on the natural resources is increased it would have a negative impact on the dynamics of sedimentation of the reservoir and reduce the lifespan.

From the local approach can be concluded that cutting the immediate slopes of the reservoir has a major impact on the generation of erosive material and a complete transport in the reservoir because of the very short transport distance. With increase of the transport distance it also increases the difference between produced erosive material and erosive transported sediment, so a part of the sediment remains in the catchment and never gets in the reservoir. On the other hand, the area which is clear cut is very large, which are taken just as an example shown in the model, but in practice such cuttings should be avoided, reduced or completely banned.

In the ninth chapter, which is a compilation of all previous, the procedure it is presented for the establishment of protection zones around water reservoirs in terms of erosion. If the previous chapters are taken into account, zoning methodological procedure can be grouped into four main steps:

- Separation of critical catchment in terms of erosion by the methodology of S. Gavrilovic.

The critical catchments from aspect of erosion are separated from the map of specific transport of erosive sediment material at the catchment level (Gsp), with reclassification of values for each sub-catchment area Gsp the following classification: IV category (<70 m^3/km^2/year) III (71-200), II (201-300) and I category (> 301 m^3/km^2/year). These categories represent the basis for zoning catchment of reservoirs in terms of erosion.

- Identify areas of accumulation on the large tributaries of the reservoir

The determination of zones of accumulation is done to separate the catchment to sub-catchments which are that directly depositing large part of the sediment in the reservoir and sub-catchments that most of sediment is deposited in the morphological expansions. In the catchment of the reservoir "Kalimanci" only the river Bregalnica is taken into consideration. Because 75% of the incoming erosive sediment is deposited in the morphological expansions, there are two zones delineated, before and after the morphological expansions. The last morphological expansion is Delchevsko Pole and as border between the two zones, the profile "Ochipale" is taken. Therefore all sub-catchment entering the second zone of deposition, the values of critical catchment in terms of erosion are reduced by one value. So if a sub-catchment area is in the first category under critical catchment in terms of erosion and enters the second zone of deposition, then would automatically be lowered into the second category of criticality. If sub-catchment is in the first category under critical catchment in terms of erosion and enters the first zone of deposition, then it retains its value for criticism.

- Allocation of immediate bank of the reservoir

According to the model of "local" approach it can be concluded that the immediate banks of the reservoir are particularly critical in terms of erosion. Therefore immediate banks of the reservoir should be separated. Under immediate coast means the distance between the maximum level of the reservoir and the highest point of water can come directly to the accumulation with the exception of the immediate tributaries of the reservoir. The separated immediate banks should get the highest category of criticism or in other words enters the first (I) zone of protection.

- Separation of the buffer zone around the reservoir

In the Law on water there is an article, according to which buffer zone to protect the reservoirs should be with width of 50 m from the maximum level of the reservoir. For the purpose of this zoning, this zone has increased the width of 100 m from the maximum level of the reservoir.

Aim of the research

The aim of the research is erosion, transport of erosive sediment, filling the reservoirs with sediment and the impact of anthropogenic activities on the above mentioned occurrences and processes.

Information of the state of area of interest

With the introduction of GIS / RS techniques in the last 25 years the modeling of erosive processes and sediment transport, from purely numerical, grown into spatial-numeric. There are many methods and approaches to defining these processes, but each of them has its

advantages and disadvantages. Anthropogenic impacts on erosion processes are long researched, but lack research for determination of the spatial extent of the sediment transport. The literature review did not find reference in defining reservoir risk zones from erosion point of view. This was the ultimate objective of this doctoral dissertation.

Short description of the applied methods

The general methodological framework consists of two parts - field observations and measurements and office analysis and data processing. Given the specifics of individual chapters, appropriate methods were used and presented in the previous text.

A brief description of the results of research

The developed methodology for zoning of catchment areas of reservoirs in terms of risk of erosion is the final result of this thesis. All other results from the survey (defining changes in land use, defined quantities of deposited sediment in reservoirs, defined dynamics of accumulation of erosive sediment, defined geospatial parameters - erosion factors, defined values of produced erosive material and transported erosive sediment, defined areas of erosion and deposition of sediment especially in the main basin, influences of land use changes, specially the impact of logging) is a function of the end result. The model resulting from this study should facilitate and visually bring closer the zoning of the land in the catchment of the reservoir in terms of erosion in the catchment and the dynamics of its deposition with erosive sediment.

ASSESSMENT OF THE THESIS

The thesis of the candidate Mr. Ivan Minčev, entitled “Development of methodology for determination of protection zones around water reservoirs from aspect of soil erosion and sediment transport” is research that includes not only the relevant areas of research but more wide areas of research witch are distributed in two research fields: technical and technological sciences – Civil engineering and water economy – soil erosion and torrent control and bio-technical sciences - land and hydrology, which provides a significant contribution to the science and practice. The approach and the procedures that are defined by the survey are general and applicable to the whole country and beyond. The thesis of the candidate Mr. Ivan Minčev, entitled "Development of methodology for determination of protection zones around water reservoirs from aspect of soil erosion and sediment transport", in the opinion of the Committee, fulfills the basic requirements and standards for preparation of doctoral thesis.

During the preparation of the doctoral dissertation, the candidate published reviewed research papers which are part of the research for his doctoral dissertation:

Mincev Ivan: “Quality assessment of some input parameters used for modeling of natural processes”, објавен: ", International conference on land conservation – LANDCON 1209, Sustainable management and climate changes, 17-21, September, 2012, Danube region, R. Serbia

The next paper is accepted for publication:

Mincev Ivan: „ Measuring deposed sediment in small reservoirs, case study: “Gradče” reservoir “, Journal: The "Agriculture and Forestry", No. 61 Issue 2; **ISSN:** 0554-5579 (Печатено), **EISSN:** 1800-6492 (Online), **COBIS.CG-ID:** 3758082

CONCLUSION AND RECOMMENDATION

The main scientific contribution of the candidate is developing an original method for defining protection zones around water reservoirs in terms of erosion and sediment transport. This methodology can be used to define these areas for all reservoirs in the country and beyond. All results obtained in the survey (contour measuring of reservoirs, defining the specific factors of erosion in GIS environment), which were aimed at the final aim may be used for other research on the issue, as in the Republic, so in region and beyond.

Given the above, the Committee proposes the teaching-scientific board of the Forestry faculty – Skopje to accept the positive assessment and schedule a defense of the doctoral dissertation of the candidate Mr. Ivan Minchev titled "Development of methodology for determination of protection zones around water reservoirs from aspect of soil erosion and sediment transport”.

COMMITTEE

1. Professor Dr. Aleksandar Trendafilov, UKIM, Faculty of Forestry- Skopje, President

2. Professor Dr. Ivan Blinkov, UKIM, Faculty of Forestry- Skopje, mentor and member

3. Professor Dr. Stanimir Kostadinov, UB, Faculty of Forestry- Belgrade, member

4. Professor Dr. Cvetanka Popovska UKIM, Faculty of Civil Engineering- Skopje, member

5. Professor Dr. Nikolčo Velkovski, Faculty of Forestry- Skopje, member