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STUDY ON SOIL EROSION HAZARD ON DETAILED LEVEL BY DIGITAL TERRESTRIAL STEREOPHOTOGRAMMETRIC METHOD (PART 2)

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Problem statement

As it was noted in first part of the publication, the problem of protecting soils from erosion is becoming increasingly important, and therefore it is necessary to develop new methods of research of soil erosion [1,5]. Particular attention should be paid to flush monitoring of ablation processes as well as convenient and effective methods of research, considering both cost and accuracy of unknown quantities. So, the question is to study universal methods of researching soil erosion that would give possibility to obtain maximum information, both quantitative and qualitative. This method was proposed by the authors in an earlier part of the publication, but direct process of the research of dependence of soil erosion from the angles of inclination has not been tested fully.

Relationship to important scientific and practical problems

Remind from the previous publication that scientific researches clearly show: soils are not only primary means of agricultural production, but also an essential component of terrestrial ecosystems, powerful accumulator of energy on the Earth, regulator of the composition of the atmosphere and hydrosphere, reliable barrier to the migration polluting substances [5].

Analysis of recent research and publications devoted to solving this problem

In [4] it is presented at a modern level the situation concerning soil erosion. The monograph is devoted to the methodological, methodical and practical issues of erosion study. The results of many years water erosion studies presented, new approaches to mathematical modeling of erosion and soil formation processes, calculation, prediction and justification of the rational use of dangerous erosion of land made on the basis of international experience are identified. It is shown and proved solving various problems of erosion study using geographic information (GIS) technology.

Work [3] focuses on the fact that for monitoring of soil and creating databases of geographic information systems (GIS), the most appropriate and cost-effective solution is to use technologies of remote sensing (RS). The description of the experimental laboratory devices for the studied land parcels is presented. Using the apparatus the ascending radio thermal radiation was measured the at an angle of 100 degrees from the zenith on horizontal polarization at wavelengths of 3.6, 5, and 11 cm and in some experiments at a wavelength of 15 cm. The following is a description of radiometric methods of measurement used for the study of the characteristics of different soils. The analysis of measurement errors is implemented. Fluctuation sensitivity threshold was 0.5 K at the time of accumulation t = 1sec for radiometers at wavelengths $\lambda = 3,6$, $\lambda = 11$ i $\lambda = 15$ cm and 1 K when t = 16sec for measuring instrument PK7 – 20 at wavelengths $\lambda = 5$ cm.

Error of absolute calibration was there 1,5-2,5 K for all wavelengths. Each cycle started after artificial irrigation or natural rain fall and finished when the moisture of the upper layer reached thickness of 0-3 cm less than 0.03 cm^3.In process of radio measurement of temperature brightness of site at the same time there were implemented measurements of thermodynamic temperature on the depth 0.5cm and 1.5cm and periodical (2-3 times per day), measurements of moisture and density of upper layers 0-1cm, 1-2cm, and 2-3 cm by thermostatic- weighting method.Sofortodaypreferencesinresearchesaregiventomodelswhichcanbeusedtoimplementexperimentalworkswithsufficientaccuracy, fast and effectively. Other important factor is cost effectiveness of the modeling.

Thus, the analysis of the literature showed that the topic is enough actual, especially in terms of the creation of different models for the study of soil erosion.

Unsolved part of the general problem

Part of general problem lies in the study and improvement of laboratory apparatus for determining soil erosion. One of the real ways of obtaining reliable, operational and accurate information about the process of soil erosion are the remote methods based on short-basis photogrammetry followed by analytical and digital processing of digital images. Estimation of state of soil ablation using photogrammetry means should be presented as a system which combines modern technical means, methods of data processing, their transferring, transformation, interpretation and output in term of digital, graphical, and descriptive models using additional data for evaluation of ablation processes of specific natural and geographical region.Estimation of condition of soil ablation should presented as a system which combine modern technical means and methods of data processing, transferring, interpretation and output in the form of digital, graphical and descriptive models with application of additional data for separate natural geographical region.

Statement of the task

The first stage of our research are:

- creating a model of test grid [1] with special tray and reservoir and its calibration;
- creation of stand site for filling soil with screws to simulate angles;
- determination of washed soil volumes in laboratory conditions when various inclination angles and accuracy of this parameters determination.

Mainmaterial

As in any experimental-engineering research it is necessary to implement a-priory accuracy estimation for searching volumes. First, we determine possible accuracy for determinations of coordinate of terrain points.

For this we use formulas of normal case of survey as factually we modeled this case:

$$X_{Ph} = \frac{B}{p} x_l, \quad Y_{Ph} = \frac{B}{p} y_l, \quad Z_{Ph} = -\frac{B}{p} f \qquad (1)$$

after differentiating them we will obtain:

$$\left.\begin{aligned} dX_{\phi} &= \frac{x_л}{p} dB + \frac{B}{p} dx_л - \frac{x_л B}{p^2} dp \\ dY_{\phi} &= \frac{y_л}{p} dB + \frac{B}{p} dy_л - \frac{y_л B}{p^2} dp \\ dZ_{\phi} &= -\frac{f}{p} dB - \frac{B}{p} df + \frac{fB}{p^2} dp \end{aligned}\right\} \qquad (2)$$

Then we will calculate mean square errors:

$$\left.\begin{aligned} m_{X_{Ph}} &= \left[\left(\frac{x_l}{p}\right)^2 m_B^2 + \left(\frac{B}{p}\right)^2 m_{x_l}^2 - \left(\frac{x_l B}{p^2}\right)^2 m_p^2\right]^{1/2} \\ m_{Y_{Ph}} &= \left[\left(\frac{y_l}{p}\right)^2 m_B^2 + \left(\frac{B}{p}\right)^2 m_{y_л}^2 - \left(\frac{y_l B}{p^2}\right)^2 m_p^2\right]^{1/2} \\ m_{Z_{Ph}} &= \left[\left(\frac{f}{p}\right)^2 m_B^2 + \left(\frac{B}{p}\right)^2 m_f^2 - \left(\frac{fB}{p^2}\right)^2 m_p^2\right]^{1/2} \end{aligned}\right\} \qquad (3)$$

where:

$m_{X_{Ph}}, m_{Y_{Ph}}, m_{Z_{Ph}}$ – mean square errors of coordinates X_{Ph}, Y_{Ph}, Z_{Ph};

B = 250 mm – length of survey basis;

x_l, y_l – 11mm, 7mm – coordinates of outer points of image;

p = 7 mm – mean value of X-parallax;

f = 50 mm – focal distance of camera;

m_B = 0.1 mm – error of survey basis measurement;

m_{x_l}, m_{y_l}, m_p = 0,005 mm – mean square errors of measurements of image coordinate x_l, y_l and parallax p on DPS «Delta-2»;

Y_{Ph} = 2500mm – distance to the object;

Put the values in the formula (3) we calculate mean square errors: $m_{X_{Ph}} = 0{,}6мм, \; m_{Y_{Ph}} = 0{,}4мм, \; m_{Z_{Ph}} = 1мм,$

As final values are soil volumes then lets calculate relative errors of volume determination using formula[6]:

$$\frac{M_v}{V} = \sqrt{\left(\frac{M_s}{S}\right)^2 + \left(\frac{M_{h\ \text{сер.в}}}{h_{\text{сер.в}}}\right)^2}; \qquad (4)$$

Here M_S^2 – is square of mean square error of area which is determined by the formula:

$$M_S^2 = 4a^2b^2\left(\frac{m_B}{B}\right)^2 + a^2b^2\left(\frac{m_f}{f}\right)^2 + \frac{2Y_0^2 \cdot b \cdot \Delta Y}{f^2} m_x^2 + \frac{Y_0^2 \cdot b \cdot \Delta Y \left(X_0^2 + a^2\right)}{2B^2 \cdot f^2} m_p^2 + \frac{Y_0^2 \cdot a \cdot b \cdot \Delta X \left(Y_0^2 + 3b^2\right)}{B^2 \cdot f^2} m_p^2 \qquad (5)$$

where: a=560 mm – size of massive on axis of abscissa;

b=600 mm – size of massive on axis of ordinate;

$\Delta X, \Delta Y$=40 mm – size of a rectangle side of the frame;

m_f=0,005 mm – error of focal distance measurement;

Considering that $\frac{Y_0}{B \cdot f} = \frac{1}{p}$, we will obtain final formula for determination relative error of area:

$$\left(\frac{M_s}{s}\right)^2 = 4\left(\frac{M_b}{B}\right)^2 + \left(\frac{m_f}{f}\right)^2 + \frac{2B^2\Delta Y}{a^2 b \cdot p^2} m_x^2 + \frac{\Delta Y\left(X_0^2 + a^2\right)}{2a^2 b \cdot p^2} m_p^2 + \frac{\Delta X\left(Y_0^2 + 3b^2\right)}{ab^2 + p^2} m_p^2 \quad (6)$$

After calculation we will obtain $\left(\frac{M_s}{s}\right) = 0{,}1\%$.

Mean square error of elevation is calculated by the formula:

$$M_{hcce.в}^2 = h^2\left[\left(\frac{m_B}{B}\right)^2\right] + \left(\frac{B}{p}\right)^2 m_z^2 + \frac{B2 \cdot m_{\Delta z}^2 + h^2 \cdot m_p^2}{L \cdot p^2} \quad (7)$$

where: h = 7mm – mean elevation;

L = 210 – number of cells in the frame;

$m_{\Delta z}$ =0,007мм – error of elevation measurements on the model;

$\frac{m_b}{B} = \frac{1}{2500}$

Placing these values in formula (7) we will get - $\frac{M_h}{h} = 0{,}3\%$

According to calculations on formulas (6) and (7), and formula (4) the relative error of volume will be: $\frac{M_v}{V} = 0{,}4\%$

Description of the experiment. Laboratorial model of the research is flowing test site consisting of tray with analogue of soil (in this case fine grained sand with volume$V$=40000cm^3), special devices for flow direction and flow collector (Fig.1). Additionally on the sides of the platform clamps handles mounted, through which it is possible to set inclinations of slope.

Fig.1. Flowing platform

On flowing platform a steel frame with stretched (in width and length) invarwire at intervals of 4 cm was installed. It was fixed at the intersections with frame and among themselves by soldering. It creates the grid which is main element in the research. Steel frame sizes: 80×68 cm, the size of the working surface 60×56 cm [1].

Lets present more detailed each of stages of experimental works.

Digital camera Canon EOS 450Dwas used for stereophotogrammetric survey. Before works there weredetermined elements of interior orientation and distortions by proper methods. [2]. Technical parameters of camera are presented in the table 1.

On the first stage the flowing test platform and the grid was mounted with inclination ω=10º. Stereopair of digital images was obtained with basis B=250mm and distance from camera to the grid Z=2500 мм (Fig.2). Using watering can it was implemented the water flow with volume 8 liters. Time of flowing was 40 sec. After ablation the survey was repeated (Fig. 3).

Table1

Technical parameters of camera Canon EOS 450D

Matrix	
The total number of pixels	12.4 million
The physical size of the frame	22.2 x 14.8 mm
Maximum resolution	4272 x 2848
Colour depth	42 bit
Number of effective pixels	12.2 million
Matrix type	CMOS
Sensitivity	100 - 1600 ISO, Auto ISO
Survey mode	
Survey speed	3.5 frame. / sec
The aspect ratio	3:2
Maximum seriesof images	53 for JPEG, 6 for RAW
The timer	2, 10 sec
The Field of vision	95%

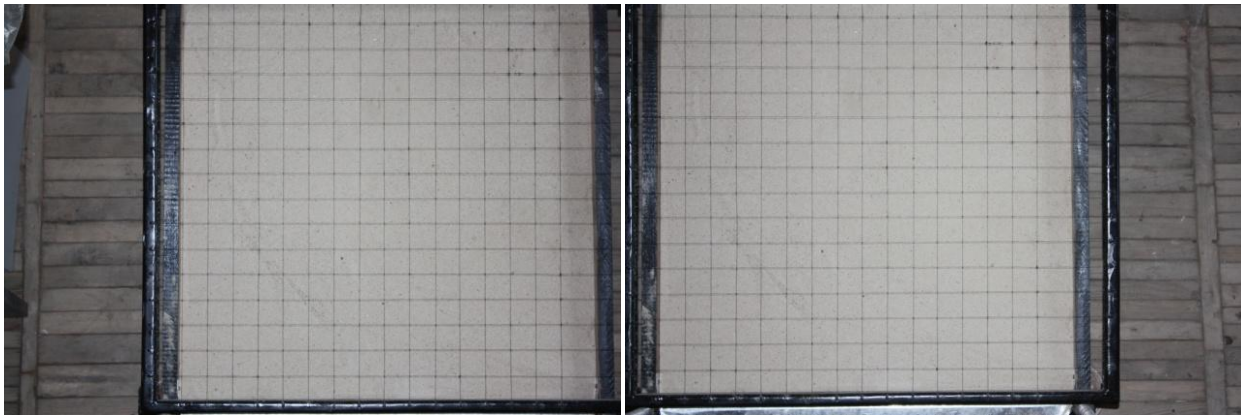

Fig. 2.Left and right image before «ablation»

Fig. 3.Left and right image after «ablation»

Then surface of sound was dried and leveled and next surveys with inclination of the test platform with 5º and 2º were implemented.

So in result 12 images (6 stereopairs) were obtained.

For their processing the digital photogrammetric complex “Delta-2” was used. Next stage was implementation of exterior orientation using control point and creation of DEM using software “Digitals”. This product includes programs Models.exe, Triada.exe, Geodesy.exe, main basic program Ged.exe and some other. For the work we used Models.exe and Ged.exe [7].

After exterior orientation theresultsofa-priory and real accuracy estimations were compared. The result of comparison for one stereopair is presented in table2.

Table 2

Resultsofexteriororientation of one stereopair

№ of control	ΔX (mm)	ΔY (mm)	ΔZ (mm)
1	0,00	-0,13	-0,20
2	0,27	0,27	0,41
3	0,18	-0,18	-1,38
4	0,01	0,48	1,53
5	-0,09	-0,43	0,52
6	0,27	-0,06	-1,38
7	-0,12	-0,10	1,01
8	-0,07	-0,06	0,23
9	-0,17	0,00	-0,79
RMSE	0,16	0,25	0,96

Analysis of comparison results shows that for all stereopairs obtained accuracy does not exceed a-priory accuracy and is correspondently: $m_{X_{Ph}} = 0{,}24мм,\ m_{Y_{Ph}} = 0{,}33мм,\ m_{Z_{Ph}} = 0{,}82мм$

For DEM creation the measurement mark was sighting on the surface of the sand in each grid square, approximately in the same place (higher left corner).In such way the DEMs of zero cycle (before ablation) and first cycle (after ablation) were created for inclination of the platform on 2º, 5º, and 10º. 3D models of the DEM of zero and first cycle are presented on Fig. 4 and Fig. 5.

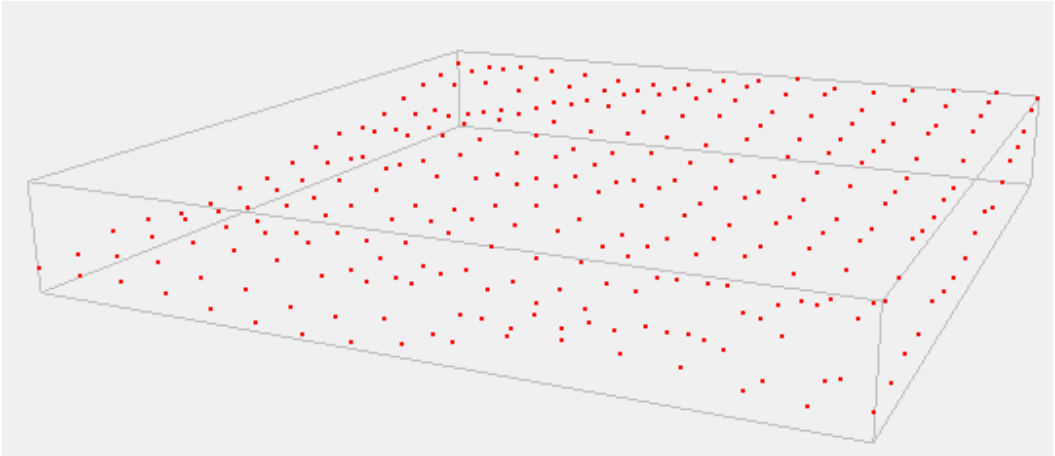

Fig.4.3D view of DEM of zero cycle

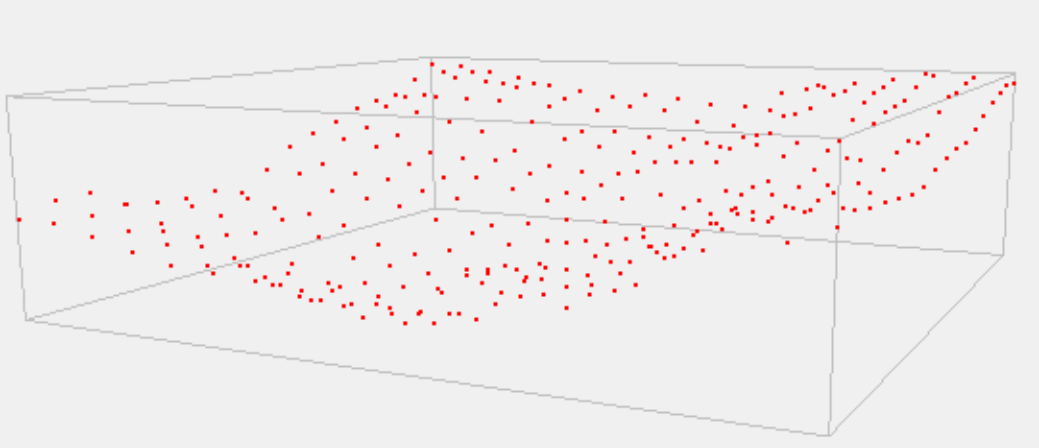

Fig.5.3D view of DEM of first cycle

The process of determining the volume was carried out in the program Ged.exe. DEM was contoured with rectangle frame. Parameter of the frame height was selected thus to be bigger than highest point of the DEM. Next the conditional volume of created shapes was calculated.

Such actions were implemented for all DEM of zero and first cycles. Results are coinditional volumes of the shapes. Taking remainder of conditional volumes for zero and first cycle we obtained value of real volumes, which are presented in the table 3.

Table 3

Values of volume of washed soil

$\omega°$	Volume of zero cycle V' (sm^3)	Volume of first cycle V'' (sm^3)	Real volume of washed soil $V= V''-V'$ (sm^3)
10	8125,7	9465,0	1339,3
5	13003,1	13386,9	383,8
2	8975,7	9111,9	136,2

An important condition for the purity of the experiment is that the frame which countered the DEM created before ablation should be copied and pasted into the DEM created after ablation and should not be created newly.

For determination of correct estimation of accuracy of washed soil volumes the real volume of the sand was calculated. Washed sand was put into some container that is shaped like truncated pyramids. The upper and lower base is a rectangle. Required parameters of this container were measured using calipers. Inserting data into the appropriate formula we obtained standard valuesfor the volume:

$V_{10°} = 1332{,}12 sm^3$; $V_{5°} = 379{,}8 sm^3$; $V_{2°} = 132{,}3 sm^3$.

Relative errors of volumes are:

$$\frac{m_v}{V} 100\% (10°) = 0{,}5\% ; \quad \frac{m_v}{V} 100\% (5°) = 1\%;$$

$$\frac{m_v}{V} 100\% (2°) = 2{,}9\ \%$$

Conclusions

As a result of the research the following conclusions should be done:

1. Determination of volume at 10º inclination of flowing platform does not exceed the preliminary estimation of accuracy that indicates the applicability of the proposed method to solve this problem.
2. Regarding the assessment of the accuracy for the slope of 5º and 2º, they basically are within tolerance of volume errors for ablation (2-3%).
3. Discrepancy of errors for the determining the volume for slope 2°and 5ºis because not completely dry sand but slightly wet was used for the experimental work. This caused a corresponding subsidence of the sand and thus higher error of determining desired volumes.
4. It is planned in the future to conduct testing of the proposed technique in the field conditions.

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Study on soil erosion hazard on detailed level by digital terrestrial stereophotogrammetric method
(part 2)

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The series of experimental researches were implemented using proposed method of determining the volume of eroded soils on stereo images obtained by non-metric digital camera to determine the real accuracy of the method Conclusions are that the method can be applied in the field conditions.