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MONITORING OF SOIL EROSION IN THE YAKKABOG RIVER BASIN AND ITS IMPACT ON AGRICULTURAL AREAS

Azamat Jumanov – PhD, Sh.Daminova – student of "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University

Abstract

This study analyzes soil sealing and its repercussions in the loss of fertile soils, which are more appropriate for agriculture use. Also, soil sealing increases flood risk. The main objective is to estimate soil loss by sealing in the Yakkabog River Basin (Kashkadarya, Uzbekistan) between 2010 and 2020. The combination of digital processing (Normalized Difference Vegetation Index (NDVI), principal components and convolution filters) of satellite imagery with the digital terrain model helps to detect risk areas and allows quick updating of sealed soil mapping. The supervised classifications of the images were used to estimate the actual soil loss by sealing in the Yakkabog River Basin and the types and agrologic classes that have been lost. Soil loss occurs to a greater extent in highly permeable soils (sands) and in the most fertile soils. The main sealed soil associations are luvisols (alfisols), regosols (entisols) and cambisols (inceptisols).

Keywords: soil erosion, impact, remote sensing, Kashkadarya.

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1. Introduction: Many studies analyze urban growth and its implications for planning and land use. Urban development often prioritizes viability and economic profitability over environmental criteria. In periods of a significant decline in agricultural, livestock farming and forestry activities, little attention has been paid by urban planning to soil quality, and considerable sealing of high or medium quality soils has taken place. This is a serious environmental problem that has been analyzed by various authors on different scales. Estimated soil loss from sealing was 9% in Europe from the mid-1980s to the late 1990s [2], 7% in the city of Nanjing in China 1984–2003 [3], and 4.5% in the US during the 1990s [4]. Soil erosion sealing is a direct result of urban growth and is seldom included in environmental impact assessments. Some of the changes that it triggers in ecosystems have been minimized, including variations in the water balance [5]. Soil erosion alters the water cycle and increases flood risk due to ground impermeability. This impermeability is irreversible when sealing is due to artificial materials, but where there is only soil compaction with no artificial cover, it may be reversible. For this reason it is essential to maintain open, unsealed zones in urban areas or, where sealing is unavoidable, to use "semi-sealing" which leaves some infiltration capacity in green spaces, recreation areas, etc. The most serious impact occurs when the underlying subsoils are highly permeable [6] and the greater surface run-off increases the quantity of sediments and contaminants. It would therefore be preferable to build on low-infiltration-capacity soils (clays) and minimize the sealing of the most permeable soils (sands) to facilitate infiltration. Urban planning should take hydrological properties or soil permeability into account to a greater extent [7,8]. This study analyzes soil sealing and its repercussion on the loss of fertile soils, which are most appropriate for agricultural use. Soil erosion also has a negative impact in terms of increased flood risk. A methodology is proposed to monitor and evaluate soil sealing using satellite images available worldwide [9]. These land-monitoring techniques should be incorporated into thematic cartography for use by local authorities. In methodological terms, this article includes a digital analysis (radiometric, spectral and spatial enhancement) of Spot images, compared with only the visual interpretation of satellite images to detect and measure soil sealing in Spain. This study also evaluates soil loss, taking into account the soil type and its agrological capacity.

For this case study, a highly dynamic area of urban development in central Spain was selected, where soil sealing has increased significantly over the last 30 years. Remote sensing facilitated the location of the sealed areas and the continuous monitoring of the changes that have occurred, although it is often difficult to define these areas exactly unless high spatial resolution images are available. This problem was solved using information obtained from large-scale aerial photos and in situ verification. However, the lower temporal resolution of photogrammetric flights (at five- or ten-year intervals in Spain) versus the continuous updating of satellite images led to the conclusion that detecting soil sealing by processing satellite images is a better approach. Mapping soil erosion using images is not always straightforward due to the heterogeneity of built-up surfaces, which are often mixed with natural areas, and to the wide range of construction types: housing, industrial buildings, communication routes, recreation areas, etc. Other authors have attempted to solve this problem proposing different analysis methods, with significantly different results depending on the required precision and the case study environment. Ridd considers that soil texture is an important factor to take into account in a model using remote sensing and considers the V-I-S (vegetation-impervious-soil) model useful for urban studies [10]. Nizeyimana uses the Soil Rating for Plant Growth SRPG model based on the Digital General Soil Map of the United States (STATSGO) soil and landscape attributes and climate [11]. Wu, 2004, developed a normalized spectral mixture analysis SMA method to quantify urban composition within the framework of the V-I-S model [12]. Valera et al. used photointerpretation of aerial photographs and Geographical Information System GIS-based map analysis to establish changes in land use from 1956–2006 in a Mediterranean area [13]. Kampourakiet al. used a maximum likelihood classification of Normalized Difference Vegetation Index (NDVI) images derived from Quick Bird data and aerial photographs [14]. For this study, the NDVI was selected and supervised classification was carried out using the parametric rule of minimum distance as this obtained the best results in a semi-arid area with sand- and clay-rich detritic sediments [15].

The main objectives of this paper are to:

- Assess the surface areas that still allow some soils to be used for agriculture.
- Calculate the percentage of soil sealed over the last 50 years from a multi-temporal analysis of satellite images and aerial photographs.
- Determine what type of land the sealing process affects.

- Analyze the surface horizons of the most fertile soils to discover the physical and chemical properties lost through sealing.
- Perform a semi-automatic classification of sealed surfaces from the image obtained with the most suitable spectrum improvement.
- Compare results of the classifications with the actual terrain and available digital cartography.

2. Study Area

Here sealing is analyzed for soils in the Yakkabog River Basin near Kashkadarya, Uzbekistan (37°58/-39°32/, 64°23/-67°42/) (Figure 1), with an area of 3220 ha. This area of highly permeable soils has undergone a significant increase in sealing in recent years. The supply to the Yakkabog River is nivopluvial, with a maximum daily flow rate of 28.1 m3/s and a maximum instantaneous flow rate of 18.3 m3/s. However, its mean flow is only 7.3 m3/s, implying significant periods of low flow.

Although the flood risk in the Yakkabog Basin is relatively low, the presence of buildings in some parts of the flood plain is a matter of concern, as historic water levels have risen more than 1 m. In addition, a reservoir at the basin head would represent an increased risk in a possible dam failure scenario. The deforestation of some areas, the extraction of aggregates and, in extreme cases, massive water discharges from a reservoir in the upper reach of the river also increase the flood risk. In 1996–1997, floods did affect the area, caused by problems that may recur in very wet hydrological years or if water is released from the reservoir.

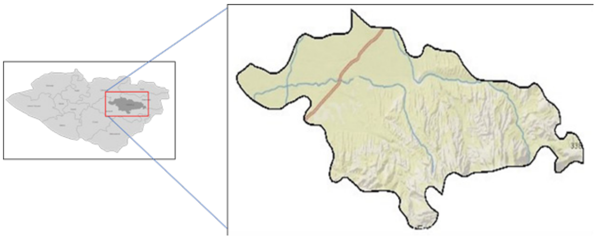

Figure 1. Study area: Yakkabog River Basin, Yakkabog, Kashkadarya.

The basin lithology is highly homogeneous and is formed by two main groups. The headwaters in the Sierra flow through Late Hercynian granites and glandular gneiss. The rest of the basin is formed by arkosic sands with gravel and clay layers prone to alteration. There is also a clear decrease in sand grain sizes and more clays towards the lower reaches of the river, increasing the risk of erosion. The river channel is confined within a gently sloping valley, flanked by remnants of multiple terraces; the highest of these are predominantly gravels, gradually becoming increasingly sandy downstream. In the lower reaches, the valley widens and becomes flatter, blurring the outline of the terraces. Here the slope contributions and remobilization of material by lateral fans become especially significant and are fundamental in the channel supply during flooding. The flood plain is not well defined and has a maximum width of 1 km in the lower reach [16].

Two features condition the flood risk: In this river, the morphological and sediment logical limits between the high water channel and the flood plain are not clearly defined and the sandy banks are very unstable, facilitating remobilization. Another significant effect is the subsurface bank erosion process resulting from the sandy composition, the intercalations of clay materials, and the elimination of protective vegetation. The result is that gullies of up to tens of meters long have formed on the banks, with various housing developments built on them.

3. Material and Methods

In this paper, the two thematic classifications to calculate the loss of soil due to sealing in the last 50 years are compared. The surface affected by soil sealing on the dates analyzed was obtained by photointerpretation and digital image processing. The urban core and road infrastructures on different dates are digitalized and the surface of discontinuous sealing (between 5%–50%) and continuous sealing (>50%) is calculated. Further, in the satellite images the urban surfaces of other non-sealed soil cover are separated (bare soil, wasteland and vegetation). These classes cannot be manually separated in the aerial photography due to the limitations of scale and the lack of infrared channels that would add spectral information about the vegetation.

Aerial photographs were used for the period 1961–1967 [17]. Panchromatic, multispectral Spot-5 satellite images from 27 August and 28 November 2011 were obtained from the National Geographical Institute.

Soil loss from sealing in the 1960 s was measured from the visual interpretation and manual digitization of aerial photographs in the Yakkabog Basin. The image obtained is a mosaic of the existing photos from 1961–1967. Although the dates do not coincide throughout the basin, there is no other existing material to build the image of this period.

The Yakkabog Basin, where the soil sealing was analyzed, was overlaid on the Digital Terrain Model (DTM) and all the images were geo-referenced to Universal Transverse Mercator UTM coordinates (grid zone 30T) and Datum ETRS89. The DTM was obtained from the Shuttle Radar Topography Mission, Global Land Cover Facility Internet server [18], with a Capture Resolution of 3 arc second (90 m of spatial resolution) [18,19].

The Spot images were processed with Erdas Imagine-2011 software, carrying out different spectral enhancements (NDVI, principal components and band combinations), radiometric enhancement (histogram equalization) and spatial enhancements (convolution filter 3 × 3 and the resolution merge of panchromatic and multispectral images). These techniques attempt to highlight different land uses in the images and are based on the following parameters:

\- NDVI (Normalized Difference Vegetation Index): this index differentiates the high spectral response of vegetation in the near-infrared band from the low response in the red. Sealed soils have negative values. The mathematical algorithm is:

$$\mathrm{NDVI} = \frac{(NIR - Red)}{(NIR + Red)}\ ; \qquad (1)$$

\- The principal components factor analysis is based on summarizing a large number of variables into a smaller group, with hardly any loss of information, taking the variance matrix into account. In remote sensing, the variables will be the different sensor bands and this analysis is used to obtain a new image, in which the first components will represent almost the entire variability. The urban land always has a regular geometric or spatial pattern.

-Equalization enhances the contrast in the image. In this operation the grayscale color is assigned by the digital pixel value and also by the frequency distribution of the orthogonal digital numbers, so that the visual number assigned to each digital number is proportional to its value and frequency. Although histogram equalization is a routine method, it has been selected in this case because it clearly shows the different soil covers, highlighting anthropic elements (buildings and infrastructure).

-The convolution filter enables improved separation of the linear elements, as these are poorly represented in the original images. This filter sums the values of a pixel and its 3 × 3 neighborhood to obtain a better spatial representation of cultivated cropland, riverbank vegetation and garden surfaces.

-Resolution merges between panchromatic and multispectral channels: To improve the detail in the final image the multispectral image has been merged with the panchromatic satellite image.

Previous work has shown that part of the surface digitized as sealed soils corresponds to an open urban type, which leaves large non-built (i.e., non-sealed) areas [17,18]. To assess the real surface with irreversible loss of soil infiltration capacity, supervised classifications by the parametric rule of minimum distance were carried out by setting up five categories of soil occupation, three of which are related to sealing and two are related to undeveloped land: bare soil (<5% sealed soil), discontinuous sealing (5%–50% sealed soil), continuous sealing (>50% sealed soil), vegetation, wasteland, in the photos and images dating from 2001–2009 and 2011, respectively.

A confusion matrix was used to check the accuracy of the classifications, contrasting the results with the existing maps on both dates [17] and with the ground truth data verified in September 2011. Although the most recent orthophotos of Yakkabog (Yakkabog Community, 2010; Scale 1:5000) enable high precision visual interpretation confirming the field data, 50 random sampling points were chosen and their accuracy was checked. These samples were taken only on surfaces classified as sealed soil (continuous and discontinuous) with a random distribution of points.

Calculation of the sealed soil surface also included the digital processing of road infrastructures, as the vectorial layers with this information tend to refer to lines. It was considered that the soil used for linear infrastructure should not be ignored in the soil sealing analysis.

4. Results and discussion

One of the main factors determining soil fertility is its water-physical properties. Here, mainly soil density, volumetric and specific mass, total porosity, water permeability, and moisture capacity are of great agronomic importance [7]. The water-physical properties of the soil vary depending on the type of soil, mechanical composition, structure, amount of organic and mineral substances, structure, culture, and level of tillage [12]. Pasture soils are soils with naturally favorable water-physical properties. In this case, this type of soil determines the air, heat, nutrients, water regime and the activity of microorganisms, as well as the growth and development of plants. This is considered as one of the main factors determining the methods and irrigation regime of vineyards.

The soil of the experimental field is light gray, grazing, medium mechanical sandy soil, with a small amount of humus, and the absorption of mineral colloids is considerably fast [9]. In the upper layers, their variation varies from 8 to 9 mg.equiv. (per 100 g of soil). The primary data on the water-physical properties of the experimental field soil density, solid phase density, soil porosity, maximum hydroscopic, and moisture reserve are given in Table 1.

To calculate the amount of water used in drip irrigation networks for irrigation of orchards and the cost of irrigation to determine the net income from the garden at the end of the year is important. In the experimental field conducted in the conditions of the soils of this study area, 0.3-0.5 and 0.7 m layers of vineyard soil were irrigated by drip irrigation system with moisture supply. In this case, the control option provided 0.7 m layer of soil with moisture and irrigated in the order of 70-75-65% relative to LFMC. Fertilization norms used on the farm to feed the orchards and vineyards were 120 kg of nitrogen, 90 kg of phosphorus and 30 kg of potassium fertilizers per hectare.

Table 1.

Water-physical properties of experimental field soils.

Soil layer, cm	Density, ton/m³	Solid phase density, ton/m³	Soil porosity, %	Maximum hydroscopicity soil mass, %
0-20	1.33	2.61	52.9	5.2
20-40	1.39	2.72	50.7	5.3
40-60	1.45	2.73	48.8	5.4
60-80	1.44	2.68	48.1	5.2
80-100	1.35	2.66	47.7	5.3
0-60	1.37	2.68	50.7	5.3
0-80	1.45	2.68	50.0	5.2
0-100	1.39	2.68	49.6	5.4

Depending on the level of soil moisture, the capillary pores up to the lower layers of the soil to be high or low depend on the soil layer to be filled with water, and to be low in winter and high in autumn in sudden changes in air temperature. LFMC of the soil is understood to be the ability to retain water in layers that have been absorbed into the soil to varying degrees [8]. The higher the moisture capacity of the soil at the site of the experiment, the more moisture is provided in the soil for the plant.

5. Conclusions.

Remote sensing for the assessment and monitoring of soil sealing provides up-to-date and highly reliable information. This technique allows one to evaluate the potential impact of soil sealing in agricultural areas. Mapping and quantifying soil sealing using high spatial resolution satellite images gives very good results, as this study shows. These images enable the correct identification of different urban typologies, although delimiting soil sealing in open urban development with wooded areas is problematic. The digital processing of linear communication routes using polygons (not lines) allows for a more accurate calculation of soil loss from sealing. In the immediate surroundings of large cities these infrastructures can be significant. These land-monitoring techniques should be incorporated into the tools used by the relevant local authorities.

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