Boletín de la Asociación de Geógrafos Españoles N.º 56 - 2011, págs. 425-430
I.S.S.N.: 0212-9426

HYDRIC EROSION RATES IN THE REGION OF MURCIA

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I. INTRODUCCIÓN

The attempt to obtain soil loss rates has been a constant in erosion studies. In Spain, early work on erosion assessment using experimental techniques started last century at the beginning of the eighties. Much of this pioneering work took place in the Murcia Region, where numerous studies have been carried out since in order to assess soil loss in different lithologies, uses and surface areas (Francis et al., 1986; Romero Díaz et al., 1988; Albaladejo & Stocking, 1989). This work aims at showing and comparing the results of most of these studies.

In the Murcia Region there are several factors which favour erosion processes: rainfall, soil erosion and anthropic action.

II. METHODS

Erosion rates have been obtained using different scales and methodologies:

1. On a millimetric scale: (i) erosion pins (Francis, 1985; Romero Díaz et al., 2007b) and (ii) microtopographic profilers.

2. On a hillslope scale: (i) open erosion plots (Francis, 1986; Romero Díaz et al., 1988; Cammeraat (2004), (ii) closed erosion plots (Francis, 1986; López Bermúdez, et al., 1996; Romero Díaz et al., 1998, 1999; Belmonte et al., 2002; Castillo et al., 1997; Albaladejo et al., 2000; Martínez Mena et al., 1999; Boix Fayos et al., 2007; Romero Díaz y Belmonte Serrato, 2008), (iii) rainfall simulations (Francis, 1986; Francis y Thornes, 1990; Calvo et al., 1991; Bergkamp et al., 1996; Cerdá, 1997; Martínez Mena et al., 2001, 2002; Fernández Gambín et al., 1996; Albaladejo et al., 2006), (iv) topographic profiles and geomorphological transects

(Chaparro y Esteve, 1995; Romero Díaz y Belmonte Serrato, 2008; Poesen et al., 1997; Vas Wesemael et al., 2006).

3. On a basin scale: (i) experimental catchments (Romero Díaz et al., 1988; Martínez Mena et al., 2001; Boix Fayos et al., 2006; Oostwoud Wijdenes et al., (2000); Cammeraat, 2002, 2004), (ii) bathymetry of dams (López Bermúdez y Gutiérrez Escudero, 1982; Romero Díaz et al., 1992; Almorox et al., 1994; Avendaño et al., 1997), (iii) check dams of hydrological correction (Romero Díaz et al., 2007a, 2007b; Romero Díaz, 2008; Castillo et al., 2007; Boix Fayos et al. 2007, 2008; Conesa y García 2007) and (iv) geometric and topographical parameters (Poesen et al., 2002; Vandekerckhove et al., 2003; Romero Díaz et al., 2007c, 2009).

Experiments quantifying soil erosion have also been carried out on different lithologies (marls, marls and gypsums, limestones, sandstones, conglomerates, schists and phyllites) and different soil uses (fields with crops, semi-natural vegetation, forests and abandoned fields).

III. RESULTS AND DISCUSSION

1. Erosion rates on a millimetric scale

On a millimetric scale erosion has been mainly measured by using erosion pins with different purposes: calculating the volumes of eroded material in the headcut of gullies (Francis, 1985), measuring the dynamics of piping processes (Romero Díaz et al., 2009), estimating the sheet erosion in reservoirs of mining sediments (Moreno Brotons, 2007), assessing the sediments retained in check dams of hydrological correction after each period of rainfall (Romero et al., 2007c), and even checking the role of different vegetation species in retaining sediments on hillslopes. Some of the most relevant data were obtained from 51 check dams selected from the the Quípar river basin during a period of three years of sediment follow-up research (Romero Díaz et al., 2007b). Although the use of erosion pins generally provides high erosion rates, in this particular case the estimated rate was only 1.37 (t ha^{-1} yr^{-1}).

2. Erosion rates on a hillslope scale

On a hillslope scale, erosion rates have been obtained by using open and closed plots.

2.1. Open plots

In open plots, collectors similar to those devised by Gerlach (1967) were installed to know the transfer of sediments along a hillside. The first collectors were installed in the experimental area of the *Rambla de Gracia* in 1984 on a hillside with low density scrubland (López Bermúdez et al., 1986). The erosion rates obtained during a two-year period (1985-1986) ranged from 1.8 to 3.2 t ha^{-1} yr^{-1} (Francis, 1986 y Romero Díaz et al., 1988). These values coincide with those reported by other authors who have used the same method in other parts of Spain. More recently, Cammeraat (2002, 2004) carried out studies with open plots in *Cañada Hermosa* (at the headwaters of the Guadalentín basin), obtaining very low erosion values in scrublands and areas reforested with pine on limestones (0.08 t ha^{-1} on average per event). On the contrary, in marl and valley bottom areas the rates exceeded 30 t ha^{-1}.

2.2. Closed plots

From 1989 to 1999, the experiments carried out in *El Ardal* (López Bermúdez et al., 1996) on a limestone substrate with good vegetation cover, and under different weather conditions, obtained low erosion rates. From 1899 to 1997 the average erosion rate was lower than 1 t ha^{-1} yr^{-1} (Romero Díaz et al., 1998). Plots covered by scrubland provided the lowest erosion rates (0.06-0.22 t ha^{-1} yr^{-1}), followed by those where bush vegetation had been cut, but still kept some vegetation (0.43-0.94 t ha^{-1} yr^{-1}), and those which were abandoned (0.01-0.50 t ha^{-1} yr^{-1}). On the contrary, cultivated and ploughed plots provided the highest rates (0.78-1.20 2 t ha^{-1} yr^{-1}). But the highest rates were found in plots ploughed up and down, which registered a very high rate compared to the rest (5.92 2 t ha^{-1} yr^{-1})

The erosion rates obtained in *El Minglanillo* on marls were much higher. For the 1997-1999 period, the rates were 7.47 t ha^{-1} yr^{-1} on crops, compared to 0.80 t ha^{-1} yr^{-1} on scrubland and 1.12 t ha^{-1} yr^{-1} on abandoned fields.

The results obtained in the experiments carried out by the CEBAS in the plots installed in *Santomera* showed the contrast between those areas covered by vegetation and those lacking it. On the other hand, from October 1988 to September 1993 experiments carried out with urban solid refuse (USR) in the Abanilla basin, using different soil addition rates (6.5, 13.0, 19.5 and 26.0 kg m^{-2}), confirmed a noteworthy decrease in runoff and soil losses.

Research carried out for 4 years on closed plots of 30 m^2 in the *Sierra del Picarcho* (*Venta del Olivo*) in areas of burned scrubland and unburned scrubland and pine forests, showed higher rates of sediment production in the burned scrubland (0.54 t ha^{-1} yr^{-1}) when compared to the unburned one (0.03 t ha^{-1} yr^{-1}).

In different lithologies (marls, conglomerates and schists) of the Guadalentín basin Romero Díaz and Belmonte Serrato (2008) installed closed plots of 10 x 2m in places with dispersed natural scrubland and near reforested areas from 2005 to 2006. The aim was to compare erosion rates between forested and non-reforested areas. The rates obtained were very low in all the plots, being higher in marls (1.86 t ha^{-1} yr^{-1}), followed by schists (0.11 t ha^{-1} yr^{-1}) and lastly by conglomerates (0.06 t ha^{-1} yr^{-1}).

To sum up, the high number of studies carried out on closed plots showed an average range from inappreciable erosion to maximum rates of 7.5 t ha^{-1} yr^{-1}. The highest rates were found in lithologies of marls, with little vegetation, in the first years after abandonment, in burnt surface areas, in crops and especially in downslope tillages.

2.3. Rainfall simulations

There are different types and different sizes of simulators (Calvo et al., 1988; Cerdá, 1999). In the Murcia Region, the 0.25, 2 and 20 m^2 simulators have been used.

With rainfall simulations, erosion rates ranged between 0 and 14.36 t ha^{-1} yr^{-1}. The higher rates were obtained in marl lithologies and soils without vegetation and recently abandoned.

In general, simulations displayed low erosion rates, except for the cases where high rainfall intensities were applied.

2.4. Geomorphological transects and topographic profiles

The geomorphological transect method has been widely used in different studies. In the Murcia Region, this method has been applied to assess the effect of reforestation on soil erosion. The data obtained by using this method provide high erosion rates, with average rates of 105 t ha^{-1} yr^{-1} on marls and 63 t ha^{-1} yr^{-1} on conglomerated in terraced slopes for reforestation.

When assessing erosion with longitudinal profiles, rates were also high in the studied areas. In areas with metamorphic lithologies, the rates obtained in slopes with almond groves (26.6 t ha^{-1} yr^{-1}) were very similar to those obtained in terraced areas for reforestation (29.4 t ha^{-1} yr^{-1}). In sedimentary lithologies, values were very high on conglomerates (103.6 t ha^{-1} yr^{-1}) and lower on marls (67.8 t ha^{-1} yr^{-1})

3. Erosion rates on a hillslope scale

3.1. Experimental catchments

Studies made on a catchment scale in the Murcia Region are not so numerous. The first studies were carried out in small microcatchments. Those carried out in the *Rambla de Gracia* (Mula basin) on an area of 3000 m^2 date from 1984 to 1986; and those carried out in the Chícamo river basin in two small microcatchments of 328 and 759 m^2 (*Color and Abanilla*) date from 1990 to 1993. In the *Rambla de Gracia*, the erosion rates ranged from 0.08 to 2.36 t ha^{-1} yr^{-1} (Romero Díaz et al., 1988) and in the second site the rates ranged from 0.85 to 2.99 t ha^{-1} yr^{-1} (Martínez Mena et al., 2001).

From 1997 to 2003 there were experiments in catchments of greater surface areas (6.4, 7.9 and 24.3 ha) which took place in the Sierra del Picarcho. The erosion rates provided were very low compared to those in the microcatchments with mean values ranging between 0.034, 0.011 and 0.015 t ha^{-1} yr^{-1} (Boix Fayos et al., 2006).

Microcatchments displayed higher rates than basins (0.08-2.99 t ha^{-1} yr^{-1} compared to 0.011-0.034 t ha^{-1} yr^{-1}).

3.2. Bathymetry of reservoirs

The data published by different authors for the main reservoirs in the Segura basin sometimes showed different values. López Bermúdez and Gutiérrez Escudero (1982) obtained an average value of 8.3 t ha^{-1} yr^{-1} for 8 reservoirs and with bathymetries performed until 1976-1977; Soto (1990) and Romero Díaz et al. (1992) obtained lower average values of 4.3 and 4.7 t ha^{-1} yr^{-1} respectively for 11 reservoirs and with more recent bathymetries; Almorox et al., (1994) obtained a similar value of 4.4 t ha^{-1} yr^{-1} for 7 reservoirs; and finally Avendaño et al., (1997) who studied a longer period of bathymetries (until 1994), reduced the average to 3.3 t ha^{-1} yr^{-1}.

3.3. Check dam of hydrological correction

Romero Díaz et al., (2007a) studied 425 check dams in the Quípar river basin (814 km^2). They calculated the erosion rate in 195 of them, which were not silted. They took into account the quantity of accumulated sediment, the basin surface area and the date of construction of the check dams. This is a relatively simple and efficient method to estimate erosion rates in basins. However, this method requires registering data for a period of time long enough and the check dams must be distributed over the total surface area of the basin (Romero Díaz et al., 2007b). The average erosion rate obtained for the whole of the Quípar basin was 3.95 t ha^{-1} yr^{-1}. However, the variability was very high (ranging between 0.03 and 72.47 t ha^{-1} yr^{-1}). More than half of the check dams displayed a very low erosion rate (below 1 t ha^{-1} yr^{-1}); 30% showed a rate between 1 and 5 t ha^{-1} yr^{-1}; and in 8% of the check dams the value registered was higher than 10 t ha^{-1} yr^{-1}.

Studies on the check dam function in smaller basins have been carried out by other authors (Cárcavo, Rogativa and Torrecilla). Thus, Castillo et al., (2007) studied the effectiveness and geomorphological impacts of check dams on erosion control in the Cárcavo basin (a small basin of 27.3 km^2 located near the Quípar basin), where 32 check dams were analyzed**;** Conesa et al., (2004) and Conesa & García Lorenzo (2008) focused on the role of check dams in the hydrological dynamics of the Rambla de la Torrecilla (Guadalentín basin) with a surface area of 14.7 km^2. In this gully 30 check dams have been built. Boix Fayos et al. (2007, 2008) and Castillo et al., (2009) studied the effectiveness of forestry hydrological restoration projects on erosion control in relation to soil use changes in the Rogativa basin (north face of the Sierra de Revolcadores). This basin has a surface area of 47 km^2 and 58 check dams. The average erosion rate calculated using sediments contained in check dams in the Rogativa basin is 5.39 t ha^{-1} yr^{-1} (Boix Fayos et al., 2008). As in the case of the Quípar river basin, the Rogativa basin also displayed a high variability (ranging between 0.25 and 107.33 t ha^{-1} yr^{-1}).

3.4. Geometric and topographical parameters

Another way of carrying out erosion rate estimates, especially in gullies and piping areas, is by measuring directly the field, carrying out topographic liftings, vertical photographs and complementing the estimates with aerial photographs.

Poesen et al., (2002) reported data obtained in 2006 in the Guadalentín basin in rills and gullies and calculated rates of 36.6 and 37.6 t ha^{-1} yr^{-1}. Oostwood Wijdenes et al., (2000) obtained rates of 1.2 t ha^{-1} yr^{-1} in another study carried out between 1997 and 1998 in 458 gully headcuts in the Rambla Salada (Guadalentín basin). Vandekerckhove et al., (2003) obtained a higher gully retreat rate (17.4 m^3 yr^{-1}) in the Guadalentín basin by studying 12 gullies over a 40–43 year time period using aerial photographs.

Romero Díaz et al., (2009) estimated the volume of soil loss in an area affected by piping processes in Campos del Río (Mula basin). Piping processes were reported for 96 out of the 122 analyzed plots of land. When the average between the different analyzed areas was calculated, the average erosion rate per plot was 287 t ha^{-1} yr^{-1} and 120 t ha^{-1} yr^{-1}. Erosion rates higher than 100 t ha^{-1} yr^{-1} were shown in 34% of plots. This value was higher than the rates obtained in gullies, but lower than that reported by García Ruíz and López Bermúdez (2009), who obtained a value of 550 t ha^{-1} yr^{-1} in other piping areas in Spain.

IV. CONCLUSIONS

The various experiments performed in the Murcia Region in order to study erosion processes have to be highlighted. These experiments have been performed not only by the Area of Physical Geography at the University of Murcia or the Centre of Edafology and Applied Biology of the Segura (CSIC), but also by other Spanish and foreign researchers.

Different methods have been used in the assessment of erosion rates and at different scales, depending on the processes under study and quantification. For this reason, very different results have been obtained. None of the values obtained can be considered to be absolute. However, they provide orders of magnitude under different environmental conditions.

Variations in the erosion rates obtained depend on the assessment method. Lower rates have been obtained with rainfall simulations, open plots, some types of closed plots, microcatchments and catchments. Medium rates are the result of assessing different types of closed plots (crops, plots without vegetation cover and on very easily erosionable lithologies), check dams and bathymetry of reservoirs. Higher rates are the result of quantifying erosion through geomorphological transects, longitudinal profiles and geometric and topographic parameters. The highest erosion rates are the ones obtained with methods which are normally used to quantify areas with higher erosion, especially those with concentrated erosion: rills, gullies or pipes.

In general terms, erosion rates in the Murcia Region are lower than 2 t ha^{-1} yr^{-1} except for the areas of badlands, piping, much altered sectors with inadequate uses and handling. However, sometimes the rates are high due to periods of heavy rainfall. In these cases, values can be higher than 50 t ha^{-1} yr^{-1} and even higher than 100 t ha^{-1} yr^{-1}.

The highest erosion rates, regardless of the method used, have been obtained on marls, high slopes, soils not covered by vegetation and abandoned crops. In semi-arid environments, like the Murcia Region, scrubland may play a protective role as efficient as, or even more efficient, than that of forest.

However, it is impossible to extrapolate the results for erosion and sediment production from plots to basins due to the different ways in which connectivity of flows and sediments is produced. There are many different factors intervening in soil loss and the period of measurement must also be taken into account. Observation periods should be long, something that is not always possible. Therefore, the comparison of data is not always valid, even if the same method is used.

The erosion rates obtained using experimental methods on soil erosion assessment question erosion rates estimated through equations such as the USLE which, in the case of the Murcia Region, overestimate erosion rates mostly in sheet runoff areas. On the other hand, as they do not calculate concentrated erosion, they underestimate erosion in gully and piping areas.