Runoff from bounded plots in Alakowe in southwestern Nigeria

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Abstract
Runoff was measured from three bounded 4 × 25 m plots. Plot A was bare, plot B was planted with maize, while plot C was located in a degraded secondary forest. Runoff was collected from each plot and found to correlate significantly with each of rainfall amount, peak intensity and rainfall energy indices in all the plots. However, neither mean intensity nor the antecedent precipitation index correlate significantly with runoff or other erosivity parameters.

When a stepwise regression equation was fitted to runoff data, the total energy over 30 minutes (EIₚₚ) was found to be the best predictor of runoff variance in plot A with a contribution of 72.8 per cent. On the other hand, rainfall amount contributed 53.9 per cent and 64.9 per cent in plots B and C respectively. The regression equations show that all the parameters made statistically significant contributions to runoff in plot A, while only six and two variables made significant contributions in plots B and C respectively.

Explanatory models of runoff generation
The landscape is made up of flats and slopes, the latter comprising mainly pediments or footslopes, hillside, valleyside and valley head slopes. Of these, the most common is the valleyside slope. Hillslope hydrological models aim at explaining the changing status of water from the time it enters the soil through precipitation and infiltration to the time it reappears in a stream channel.

Two popular models have been advanced to explain the movement of water on hillslopes: the overland flow and the throughflow models. The first was proposed by Horton (1945) who identified rainfall intensity and infiltration capacity as determinants of overland flow. Horton visualized two main sources of water supply to a stream: overland flow and baseflow from groundwater. Rain falling on the ground infiltrates until it reaches the water table, where it is stored to supply the base-flow component of the stream. Also during rainfall, when the infiltration capacity of the soil is exceeded by precipitation intensity, water would start to collect on the surface and would eventually result in the storm runoff component of the stream hydrograph.

Horton’s model assumed a homogeneous soil on which the overland flow would occur simultaneously and uniformly all over the slope due to the decreasing rate of infiltration and surface storage. The model recognizes a critical distance from the crest over which sufficient water collects to initiate flow. Flow depth increases further
downslope until it begins to erode and to form rills and gullies. This section can cover up to two-thirds of the hillslope area.

However, while Horton's overland flow can be observed in semi-arid areas it is relatively rare in humid environments, except where the vegetation cover has been removed; otherwise vegetation cover generally prevents the generation of surface runoff.

The throughflow model emphasizes the movement of water downslope through the upper soil horizon (Leopold et al. 1964; Kirkby and Chorley 1967; Kirkby 1969; Emmett 1970). Throughflow may occur when soil permeability decreases with increasing depth at the base of the A horizon. When the water percolating through the A horizon cannot penetrate fast enough it is deflected within the upper layer as throughflow. As rainfall continues, soil layers become saturated and throughflow is deflected more and more to the surface. Ultimately the soil is saturated to the surface to produce saturation overland flow.

Saturation overland flow can occur at much lower rainfall intensities than Horton's overland flow and is much more localized, being generally found near stream channels, on concave slopes, in hollows or where the soils are either thin or impermeable. This amounts to an upslope extension of the existing channel system (Kirkby 1969).

Other workers have recognized the importance of soil heterogeneity over the watershed and the irregular pattern of precipitation both areally and temporally with regard to the generation of runoff. As these factors have created a very complex hydrologic response pattern on the land surface, various models have been developed, among which are the fixed partial area model (Betson 1964) and the variable contributing area model (Hewlett and Hibbert 1967; Ragan 1968). In all these models it is recognized that varying proportions of particular parts of a watershed regularly contribute overland flow to streams. The conclusion from most field studies is that overland flow is relatively rare in time and space, especially in humid vegetated basins. Most overland flow hydrographs originate from small portions of watersheds constituting no more than 10 per cent of the basin area, and even in these restricted areas only 10–30 per cent of the rainfall events generate overland flow. Dunne and Black (1970a,b) have shown that the contributing areas are limited to topographically low wetlands created by rising water tables adjacent to the stream.

Following experiments in the Sleepers River watershed and similar experiments in many other watersheds in humid climates, Hewlett and Nutter (1970) have proposed the variable-source-area model, which differs from the partial-area concept in two respects:

1. partial areas are thought of as being fixed in location, whereas variable source areas expand and contract;
2. partial areas feed water to streams by means of Hortonian overland flow, whereas variable-source areas are created when surface saturation occurs from below.

The importance of runoff from the variable source areas is that it is made up partly of direct precipitation on the wetlands and partly from subsurface storm flow.

A number of runoff studies have been carried out in Nigeria, among which are those by Okechukwu (1974), Ebisemiju (1979), Ogunkoya (1979) and Oyegun (1980). However, none of these studies is based on runoff generated by rainfall from erosion plots on valleyside slopes. Whereas Okechukwu (1974) studied runoff from large basins in different climatic locations, Ogunkoya (1979) studied runoff from third-order streams using staff gauges. Ebisemeju (1979) used statistical analysis to show the structure of interrelationships between runoff and erodibility parameters, but
only Oyegun (1980) studied runoff and sediment yield from different surfaces. As the results obtained from these studies comprise the gross runoff from composite surfaces, it is difficult to ascertain runoff production in relation to specific land use types.

Objectives

The aim of this paper is to relate the volume of runoff from each of three plots of varying vegetation (plot A—bare fallow, plot B—maize and plot C—forest) to the following rainfall erosivity parameters: amount, mean intensity, peak intensity, amount and intensity over 15 minutes \( (A I_{15}) \), total energy over various periods of time \( (E I_{10}, E I_{15}, \text{ and } K E > 25) \)—see below) and antecedent precipitation, with the objective of determining the effects of each of these on total runoff from each plot. In other studies, the latter variable has been recognized as the most important erosional parameter in the study area (Jeje and Agu 1982; Jeje 1987).

Study area

Ife area is in southern Nigeria and is characterized by a humid tropical climate with a mean annual temperature of 27°C and a mean rainfall of 1500mm concentrated between March and November, with a double maximum in July and September and a short dry spell in August. The onset and end of the rainy season are marked by thunderstorms with high rainfall intensity.

Study method

The present study used three bounded erosion plots at Alakowe, some 16 km by road from Ife in southwestern Nigeria (see Fig. 1). The plots are representative of the three management practices common in this part of Nigeria: a bare surface, maize and degraded secondary forest. They are all located on a first-order valleyside slope inclined at 10° in the Opa river system. The degraded secondary forest consists of three strata: the emergents 15–20m high, an irregular middle layer about 7m high and a sparse shrub layer. The surface litter layer was sparse. The slope, which is convexo-rectilinear in profile, is underlain by the Egbeda soil series, Rhodic Luvisol or Haplustalfs developed on deeply weathered fine-grained biotite gneisses and schists (Smyth and Montgomery 1962). The plots were located on the rectilinear segment of the slope profile.

Field and laboratory methods used for this study are documented elsewhere (Jeje and Agu 1982; Jeje 1987). However, it is pertinent to state that the maize density was 8100 stands ha\(^{-1}\) and the plot was mulched. The erosion plots had the following dimensions: length 25m, width 4m and 15-cm-high boundary walls. Discharge from each plot was passed through a channel into a collection tank placed in a trough. Both the collecting channels and the troughs were covered with galvanized iron sheets to ensure that only the runoff from the plots entered the tanks and also to minimize evaporation. The runoff so collected was measured with a calibrated bucket and recorded. The tank was then replaced.

Rainfall erosivity parameters for each rainfall event were determined from data derived from the automatic rain gauge and analysed following the methods outlined by Morgan (1979). The rainfall erosivity parameters are defined as follows:
Runoff from bounded plots in Nigeria

66 Runoff from bounded plots in Nigeria

Figure 1. Location of the study area.

$AI_{15} =$ total rainfall ($A$) multiplied by 15 minutes' peak intensity ($I$).

$EI_{15} =$ total kinetic energy multiplied by the maximum sustained intensity for 15 minutes.

$EI_{30} =$ total kinetic energy multiplied by the maximum sustained intensity for 30 minutes.

$KE>25 (KE>25\cdot4) =$ total kinetic energy of rain falling at intensity greater than 25mm (25\cdot4mm)hr$^{-1}$.

The most critical property of rainfall erosivity is kinetic energy. For high-intensity tropical rainfall, Hudson (1965) derived the equation:

$$KE = 29.8 - 127.5/Z$$

where $I$ is the intensity in mm hr$^{-1}$.

To compute the kinetic energy the traces on the automatic raingauge charts were analysed. The trace on each chart is divided into sections in which the slope on the chart is constant. The intensity is calculated according to the gradient and the quantity of rainfall at that intensity is noted. Once the intensity is known the kinetic energy is computed using Hudson’s (1965) equation. The energy is then summed for each storm.

Rainfall amount and peak intensity (for 15 minutes) were obtained directly from the rainfall charts while an index of soil moisture status, the antecedent precipitation index (API), was determined following Gregory and Walling’s (1973) modification of Butler’s (1957: 227–9) method:
\[ Pa = Pt \cdot \frac{1}{t} \] or \[ Pt \cdot K^t \]

where \( Pa \) = antecedent precipitation index (API)
\( Pt \) = precipitation for any given day
\( t \) = time (in number of days) since the rainfall
\( K \) = recession factor which is less than 1.00, but ranges from 0.85 to 0.98.
The smaller figure was used in this study.

Observations

Table 1 shows some of the physical characteristics of the soil based on 10 samples taken from the study area. Textural analysis of soil samples shows that the top 50cm is clay-loam, but with the percentage of sand and clay increasing steadily while the silt content decreases with depth down to 120cm.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Texture class</th>
<th>Mean % of sand (2.00–0.2 mm)</th>
<th>Mean % of silt (0.2–0.02 mm)</th>
<th>Mean % of clay (0.002 mm)</th>
<th>Bulk density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–50</td>
<td>Clay-loam</td>
<td>35.2</td>
<td>32.6</td>
<td>32.2</td>
<td>1.30</td>
</tr>
<tr>
<td>50–90</td>
<td>Sandy-clay</td>
<td>50.4</td>
<td>5.4</td>
<td>44.2</td>
<td>1.24</td>
</tr>
<tr>
<td>90–120</td>
<td>Sandy-clay-loam</td>
<td>67.8</td>
<td>4.0</td>
<td>28.2</td>
<td>1.43</td>
</tr>
<tr>
<td>120–150</td>
<td>Sandy-clay-loam</td>
<td>58.4</td>
<td>14.5</td>
<td>26.1</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Rainfall and runoff

Rainfall amount varies from year to year; for example, it was as high as 1417mm in 1980 and dropped to a low of 924mm in 1982. The rainfall peak intensity corresponds fairly well with the rainfall pattern. The highest mean intensities are recorded in May and October—at the onset and withdrawal of the rainy season. During the study period, storms with mean intensities less than 10mm hr\(^{-1}\) were dominant (38 per cent of all recorded rainstorms), followed by mean intensity storms 20–30mm hr\(^{-1}\) (20 per cent), 30–40mm hr\(^{-1}\) (20 per cent), 10–20mm hr\(^{-1}\) (7 per cent), 40–50mm hr\(^{-1}\) (4 per cent), 50–60mm hr\(^{-1}\) (4 per cent), 60–70mm hr\(^{-1}\) (3 per cent), 70–80mm hr\(^{-1}\) (3 per cent), and above 90mm hr\(^{-1}\) (1 per cent).

Table 2 shows rainfall and runoff produced from plots A, B and C between April and November 1982. As expected, runoff was generally higher from plot A (bare) than from either of the other plots, except in July and August, when it was highest in plot C (forest). Surprisingly, plot C under degraded forest consistently yielded higher runoff than plot B under maize cover, except in April. The low value in plot B was probably due to mulching management, so that this plot responded least to rainfall input, especially during periods of maximum maize cover in June and September.

Percentage runoff was highest in all the plots in April, May and October, thus
Table 2. Rainfall and runoff in plots A, B and C from April to November 1982

<table>
<thead>
<tr>
<th>Month</th>
<th>Rainfall (mm)</th>
<th>Monthly runoff (litres)</th>
<th>Runoff depth (mm)&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>April</td>
<td>142.40</td>
<td>330.30</td>
<td>100.20</td>
</tr>
<tr>
<td>May</td>
<td>171.90</td>
<td>451.00</td>
<td>79.20</td>
</tr>
<tr>
<td>June</td>
<td>151.10</td>
<td>261.60</td>
<td>88.70</td>
</tr>
<tr>
<td>July</td>
<td>78.60</td>
<td>43.17</td>
<td>19.95</td>
</tr>
<tr>
<td>August</td>
<td>29.90</td>
<td>1.20</td>
<td>1.41</td>
</tr>
<tr>
<td>September</td>
<td>133.80</td>
<td>94.50</td>
<td>37.26</td>
</tr>
<tr>
<td>October</td>
<td>152.20</td>
<td>264.10</td>
<td>77.85</td>
</tr>
<tr>
<td>November</td>
<td>14.60</td>
<td>12.60</td>
<td>0.96</td>
</tr>
<tr>
<td>Total</td>
<td>874.50</td>
<td>1458.47</td>
<td>405.53</td>
</tr>
</tbody>
</table>

Source: Data collected from the experimental station, Alakowe

<sup>a</sup> Figures in parentheses are runoff as a percentage of rainfall

 correspond to the bimodal rainfall pattern of the study area. It was highest in plot A throughout the year apart from July and August. It was only in April that runoff percentage from plot B exceeded that from plot C. This was probably because the first maize had just been cultivated; thereafter runoff from plot C consistently exceeded that from plot B. It is interesting to note that runoff from C exceeded that from A in July and August and was close to that from A in the months of September and October. However, percentage runoff was lowest from the maize plot most of the time.

Table 3. Rainfall that generated runoff in plots A, B and C

<table>
<thead>
<tr>
<th>Date</th>
<th>Rainfall (mm)</th>
<th>API</th>
<th>Peak intensity (mm hr&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>Runoff (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 April 1982</td>
<td>7.0</td>
<td>39.75</td>
<td>27.22</td>
<td>9.00</td>
</tr>
<tr>
<td>11 May 1982</td>
<td>5.4</td>
<td>68.72</td>
<td>21.56</td>
<td>12.00</td>
</tr>
<tr>
<td>1 June 1982</td>
<td>9.2</td>
<td>78.01</td>
<td>36.86</td>
<td>2.10</td>
</tr>
<tr>
<td>3 July 1982</td>
<td>0.7</td>
<td>63.43</td>
<td>2.81</td>
<td>0.30</td>
</tr>
<tr>
<td>11 July 1982</td>
<td>2.5</td>
<td>41.59</td>
<td>8.4</td>
<td>0.24</td>
</tr>
<tr>
<td>27 August 1982</td>
<td>6.5</td>
<td>14.66</td>
<td>26.00</td>
<td>1.20</td>
</tr>
<tr>
<td>2 September 1982</td>
<td>6.5</td>
<td>18.01</td>
<td>27.20</td>
<td>4.50</td>
</tr>
<tr>
<td>25 October 1982</td>
<td>2.5</td>
<td>41.01</td>
<td>10.00</td>
<td>2.16</td>
</tr>
<tr>
<td>7 November 1982</td>
<td>5.7</td>
<td>40.57</td>
<td>22.80</td>
<td>4.50</td>
</tr>
</tbody>
</table>
Table 4. Runoff in plot C (forest) as a percentage of that in plot A (bare)

<table>
<thead>
<tr>
<th>Month</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>10.1</td>
</tr>
<tr>
<td>May</td>
<td>41.8</td>
</tr>
<tr>
<td>June</td>
<td>37.6</td>
</tr>
<tr>
<td>July</td>
<td>123.3</td>
</tr>
<tr>
<td>August</td>
<td>300.0</td>
</tr>
<tr>
<td>September</td>
<td>92.1</td>
</tr>
<tr>
<td>October</td>
<td>63.6</td>
</tr>
<tr>
<td>November</td>
<td>47.8</td>
</tr>
</tbody>
</table>

The total runoff from each plot in the period under study was 1458.47, 405.53, and 638.25 l for plots A, B, and C respectively. These represent runoff depths of 14.58 mm, 4.06 mm, and 6.38 mm for plots A, B, and C respectively, produced by a total rainfall of 874.50 mm. The runoff coefficient is highest in plot A at 1.67 per cent, followed by plot C at 0.73 per cent, while it is lowest in plot B at 0.48 per cent (see Table 2).

Runoff from the plots generally ceased after each rainfall event, but sometimes it continued to trickle into the collecting tank in plot C long after it had stopped in plots A and B. On the whole, 92 per cent of the rainfall events generated runoff in all the plots. Given that only 8 per cent of the events failed to generate runoff in all the plots, the threshold rainfall generating any runoff can be said to approximate the lowest intensity/amount event in that month. Thus, as shown in Table 3, this threshold rainfall amount varied from month to month. The lowest threshold was recorded on 3 July, when rainfall of 0.7 mm and 2.8 mm hr⁻¹ peak intensity produced runoff in all the plots, with plot C having half the runoff of plot A.

Table 4 shows runoff in the forest plot as a percentage of runoff from the bare surface on a monthly basis. At the beginning of the rainy season, in April, runoff from plot C was about 10 per cent of that of plot A, but as the rainy season progressed this rose to about 42 per cent in May and about 38 per cent in June, the latter probably coinciding with the period of maximum infiltration. However, the percentage rose to about 123 and 300 in July and August respectively. As the plots were on the lower part of the slope profile, the large runoff in July and August from plot C probably represents a large volume of saturated overland flow which, as already noted, continues long after the rains have ceased. This also could be due to the fact that the forest plot storage had been effectively filled by July and thus provided long-duration drainage. For the whole of the study period runoff from the forest averaged 43.8 per cent of that from the bare surface, while runoff from the maize plot averaged 27.8 per cent of the bare surface.

Table 5 shows that runoff from all the plots correlated significantly with all the erosivity parameters except mean intensity and the antecedent precipitation index. Rainfall amount correlates highly with runoff in plots A and C while $EI_{30}$, with an $r$ value of 0.85 in plot A, has the highest correlation of all. However, the correlation between rainfall and the $EI_{30}$ index is rather low in plots B and C. In fact, all the significant erosivity parameters record high $r$ values in plots A and C.

Table 6 shows the correlation matrix for runoff and eight other erosivity parameters where:
Runoff from bounded plots in Nigeria

Table 5. Correlations between runoff from plots and erosivity parameters based on all rainfall events analysed

<table>
<thead>
<tr>
<th>Parameter</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall amount</td>
<td>0.84</td>
<td>0.73</td>
<td>0.81</td>
</tr>
<tr>
<td>Mean intensity</td>
<td>0.34*</td>
<td>0.30*</td>
<td>0.35*</td>
</tr>
<tr>
<td>Peak intensity</td>
<td>0.83</td>
<td>0.72</td>
<td>0.79</td>
</tr>
<tr>
<td>AL15</td>
<td>0.83</td>
<td>0.62</td>
<td>0.78</td>
</tr>
<tr>
<td>EL30</td>
<td>0.85</td>
<td>0.70</td>
<td>0.74</td>
</tr>
<tr>
<td>EI15</td>
<td>0.84</td>
<td>0.65</td>
<td>0.72</td>
</tr>
<tr>
<td>KE &gt; 25</td>
<td>0.67</td>
<td>0.59</td>
<td>0.53</td>
</tr>
<tr>
<td>API</td>
<td>0.38*</td>
<td>0.25*</td>
<td>0.22*</td>
</tr>
</tbody>
</table>

* Not significant at 1.0 per cent confidence limit

R_A = runoff from plot A
R_B = runoff from plot B
R_C = runoff from plot C
S_A = rainfall amount
S_B = mean intensity
S_C = peak intensity
S_D = AL15
S_E = EL30
S_F = EI15
S_G = KE > 25
S_H = API

Both mean intensity and API have the lowest correlations with the other parameters. However, rainfall amount correlates significantly with peak intensity, AL15, EL30, and EI15, while peak intensity correlates highly and significantly with AL15, EL30 and EI15.

Table 6. Correlation matrix of runoff and erosivity parameters

<table>
<thead>
<tr>
<th></th>
<th>R_A</th>
<th>R_B</th>
<th>R_C</th>
<th>S_A</th>
<th>S_B</th>
<th>S_C</th>
<th>S_D</th>
<th>S_E</th>
<th>S_F</th>
<th>S_G</th>
<th>S_H</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_A</td>
<td>1.00</td>
<td>0.75</td>
<td>0.82</td>
<td>0.34*</td>
<td>0.83</td>
<td>0.83</td>
<td>0.85</td>
<td>0.84</td>
<td>0.67</td>
<td>0.38*</td>
<td></td>
</tr>
<tr>
<td>R_B</td>
<td>1.00</td>
<td>0.73</td>
<td>0.73</td>
<td>0.30*</td>
<td>0.72</td>
<td>0.68</td>
<td>0.70</td>
<td>0.65</td>
<td>0.59</td>
<td>0.25*</td>
<td></td>
</tr>
<tr>
<td>R_C</td>
<td>1.00</td>
<td>0.81</td>
<td>0.35*</td>
<td>0.79</td>
<td>0.78</td>
<td>0.74</td>
<td>0.72</td>
<td>0.53</td>
<td>0.22*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_A</td>
<td>1.00</td>
<td>0.23</td>
<td>0.98</td>
<td>0.93</td>
<td>0.91</td>
<td>0.89</td>
<td>0.73</td>
<td>0.38*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_B</td>
<td>1.00</td>
<td>0.22*</td>
<td>0.18*</td>
<td>0.36</td>
<td>0.36</td>
<td>0.19*</td>
<td>0.01*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_C</td>
<td>1.00</td>
<td>0.91</td>
<td>0.91</td>
<td>0.36</td>
<td>0.90</td>
<td>0.75</td>
<td>0.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_D</td>
<td>1.00</td>
<td>0.86</td>
<td>0.81</td>
<td>0.64</td>
<td>0.38*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_E</td>
<td>1.00</td>
<td>0.95</td>
<td>0.72</td>
<td>0.39*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_F</td>
<td>1.00</td>
<td>0.76</td>
<td>0.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_G</td>
<td>1.00</td>
<td>0.49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_H</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: See text for explanation of R_A-R_C, S_A-S_H
* Not significant at the 1 per cent confidence limit
Multivariate relationships

The relationship between runoff and the erosivity parameters used in this study can be expressed for each of the three plots by the following equations:

\[ \log R_1 = 1.538 + \log 0.138 S_1 + \log 0.382 S_2 + \log 0.215 S_3 + \log 0.175 S_4 \]
\[ + \log 0.373 S_7 + \log 0.110 S_8 + \log 0.256 S_9 + \log 0.247 S_{10} \]  
(1)

\[ \log R_2 = 0.676 + \log 1.337 S_1 + \log 0.290 S_2 + \log 0.096 S_3 + \log 0.402 S_4 \]
\[ + \log 0.326 S_5 + \log 0.173 S_6 \]  
(2)

\[ \log R_3 = 0.201 + \log 1.246 S_1 + \log 0.344 S_2 \]  
(3)

Table 7 shows the \( r^2 \) (coefficient of determination) values which indicate the additional statistical determination produced by the inclusion of each variable on the models as they relate to runoff from each of the erosion plots, A, B and C. Both the equations and Table 7 show that rainfall is the most important predictor of runoff in plots B and C, accounting for 53.9 per cent and 64.9 per cent of the variation in runoff in plots B and C respectively. It is followed by mean intensity, which contributes 1.9 per cent and KE>25 and EZjo which contribute 0.56 per cent and 1 per cent respectively in plot B. In plot C it is followed by API, which contributes 1 per cent of the variation. On the other hand, the most important predictor of runoff in plot A is \( EI_{15} \), with 72.8 per cent. This is followed by \( AI_{15} \), a parameter which derives partly from rainfall amount, and which contributes 3.5 per cent of the variation. The next parameter in importance is \( EI_{15} \), which accounts for 1.1 per cent of the explanation.

Table 7. Coefficient of determination (\( r^2 \))^a values due to each rainfall parameter in the regression equation

<table>
<thead>
<tr>
<th>Runoff</th>
<th>Rainfall intensity</th>
<th>Peak intensity</th>
<th>( AI_{15} )</th>
<th>( EI_{30} )</th>
<th>( EI_{15} )</th>
<th>( KE&gt;25 )</th>
<th>API</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot A</td>
<td>0.0004 0.006 0.0001</td>
<td>0.035</td>
<td>0.728</td>
<td>0.0110</td>
<td>0.003</td>
<td>0.0003</td>
<td>0.783</td>
<td></td>
</tr>
<tr>
<td>Plot B</td>
<td>0.5390 0.019</td>
<td>—</td>
<td>—</td>
<td>0.010</td>
<td>0.0102</td>
<td>0.006</td>
<td>0.0012</td>
<td>0.585</td>
</tr>
<tr>
<td>Plot C</td>
<td>0.6490</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.0100</td>
<td>0.659</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Omitted values represent cases where \( r^2 \) values are 0

^a Significant at 0.01 level

On the whole, all the erosivity parameters provide 78.3 per cent of the explanation of runoff variation in plot A, while six parameters provide 58.5 per cent explanation in plot B and only two parameters account for 65.9 per cent of the runoff variation in plot C.

Discussion

This study has revealed the following information:

1. that runoff is greatest in the bare plot for the duration of the experiment;
2. that runoff from the forest plot can sometimes equal or even exceed that from the bare plot;
3. that runoff is best predicted by the $E_{I30}$ index on the bare plot, and by rainfall amount on the maize and forest plots;
4. that there is a strong correlation between all other erosivity parameters and runoff except mean intensity and API.

It is not surprising that runoff is greatest from the bare plot as this simply confirms the findings of, among others, Wischmeier and Smith (1962), Hudson (1971), Stocking and Elwell (1973 and 1976) and Lal (1976). What is surprising, however, is the high runoff values in the forest plot, as this contrasts with the findings of, for example, Hewlett and Hibbert (1967), Kirkby (1969), Reinhart et al. (1963), Rothacher (1965) and Whipkey (1969), who all worked in forested areas in humid temperate regions. However, Pierce (1967), Ruxton (1967) and Kessel (1977) observed overland flow in the forested temperate region of the United States and in tropical New Guinea and Guyana respectively. With ferruginous clay-loam soil, as in the study area, it is possible that, with the poor occurrence of surface litter, the soil can be exposed and the clay can expand after initial wetting, thus sealing the surface layer and making conditions favourable to overland flow (Tackett and Pearson 1965).

The high volume of runoff observed in plot C (forest) between May and November is not surprising because it is located close to a stream channel on the lower section of a long, vegetated slope. Runoff, which always continues long after the rains have ceased, is partly from overland surface flow through stem flow, leaf drip, and direct rainfall impact, but mainly from both saturated and unsaturated overland flow.

Generally, runoff was persistently low in the maize plot (plot B) due to mulching with maize stover and cleared foliage. This substantially reduced runoff because of increased surface detention (Borst and Woodburn 1942). Also, mulch absorbs rainwater and transmits moisture slowly into the soil, while the maize canopy intercepts raindrops so that only raindrops whose intensity has been reduced reach the surface directly; hence the contribution of mean intensity, $KE>25$, $E_{I15}$, and $E_{I90}$ indices in the explanation of runoff variation from this plot. However, between April and June, when the maize crops had not achieved maximum ground coverage and the stover from the previous season had decayed, there was very little cover to absorb rainfall impact; hence the importance of intensity parameters as predictors of runoff.

The $r$ values in Table 6 show that rainfall amount correlates highly with all erosivity parameters except mean intensity and antecedent precipitation index, being highest at 0.98 with peak intensity, 0.93 with $AI_{15}$ and 0.91 with $EI_{15}$ indices. There are also high correlations between $EI_{30}$ and $EI_{15}$ (0.95), and between peak intensity and $AI_{15}$ (0.91), $EI_{30}$ (0.91) and $EI_{15}$ (0.90). The low $r$ value between runoff and API is not unexpected as it accords with the findings of Stocking and Elwell (1973) in Rhodesia. It is conceivable that the API may not be as important as it is thought to be in the generation of runoff as the recessive influence of a previous rainfall event on the runoff generation capacity of a subsequent event depends on the elapsed time interval.

**Conclusion**

This paper has attempted to relate runoff from different land uses/vegetal covers to erosivity parameters like rainfall amount, mean intensity, peak intensity, $AI_{15}$, $EI_{30}$, $EI_{15}$, $KE>25$ and antecedent precipitation indices.

Runoff took place from all the plots but it was greatest from the bare plot, with a runoff coefficient of 1.7 per cent, followed by the forest plot with a runoff
coefficient of 0.73 per cent. The maize plot produced the least runoff.

The pairwise correlation matrix in Table 6 shows high correlation amongst variables except peak intensity and antecedent precipitation. However, when the stepwise regression model was fitted to the data collected, the result shows $EI_{30}$ to be the most important predictor of runoff from plot $A$, accounting for 72.8 per cent prediction. However, rainfall amount contributes the highest prediction in plots $B$ and $C$, accounting for 53.9 per cent and 64.9 per cent respectively.

The regression equation shows that all the independent variables made some contribution to runoff variance in plot $A$, while in plot $B$ only six made contributions, with peak intensity and the $AI_{15}$ index being negligible. However, in plot $C$ only rainfall amount and antecedent precipitation index comprised the 65.9 per cent contribution.

It would appear that more data (on slope length and gradient, for example) will be required to further explain factors influencing runoff from plots. One of the most interesting aspects of this study is the observation of overland flow in the forest, contrary to the observations made by some workers in temperate regions.

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Runoff from bounded plots in Nigeria


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