2 Erosion hazards and conservation needs as a function of land characteristics and land qualities

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2.1 Introduction

Establishing erosion hazards is a difficult undertaking as erosion is the result of many processes which influence each other in complex interactions and proceed at rates that vary with time and space. Most available assessment procedures are of a qualitative nature, based on a descriptive interpretation of the production environment. This approach has some obvious disadvantages: interpretations are only as good as the interpreter is who projects cause-effect relationships observed in other areas on a situation that is basically new to him. Reliance on personal experience is bound to make the evaluation of erosion hazards somewhat subjective and often inconsistent and irreproducible. To overcome these problems, mathematical relations have been suggested which relate observed or inferred land properties to soil loss. These relations are mostly regression equations; they lend the interpretation a quantitative appearance as their outcome is a figure instead of a qualitative class denotation. Planners, engineers and builders tend to prefer figures over less transparant qualitative erosion hazard indications in which the interpreter's doubts and reservations are so painfully present. It is questionable, however, whether this preference is justified when the figures result from a lumped parameter model, developed and calibrated for some other region, where the selection of relevant land properties was fixed just as their relative weights and the nature of interactive effects.

A qualitative assessment by an experienced erosion specialist is then more realistic and more reliable than results obtained with such abused 'simple models'. And if doubtful significance of results is the price for procedural consistency, then that price is too high.

What alternative do we have? If realistic and quantitative estimates of anticipated soil loss are to be made with standard procedures, the erosion process and its dynamics must be unravelled and described in a realistic and quantitative way. That is a difficult task involving the construction of event-oriented models of soil detachment (to establish the quantity of soil material potentially available for erosion at any time) and of overland flow/transport capacity (to determine how much soil is actually lost) in a regional setting. Years of methodological work will be needed to construct a comprehensive analytical – not just correlative – erosion model and, once it is completed and tested, its operational value will be reduced by its high requirement of accurate basic data. I think that we shall have to pass through this stage because only then can we hope to develop realistic 'simplified models' which would be useful in practical conservation work because of their limited complexity and data requirements. Such simplified models could offer the same advantages as promised by the 'simple models' that I have mentioned earlier but are vastly superior to them in that they have the perceptive basis and dynamic character required to describe erosion with some measure of accuracy.

The theme of this Workshop places the issue of soil erosion in the wider perspective of land evaluation. That is the only correct approach. Erosion involves a change in land properties and its assessment is part of any adequate description/evaluation of land. Therefore, though it is conceivable that land evaluators can, in some instances, ignore the possibility of soil erosion, a study of erosion hazards can never be realistic if detached from its land evaluation context. I have argued before that erosion, and its consequences for the environment, should preferably be described in a dynamic, quantitative way. For the very same reasons it is needed to explore the possibilities to give land evaluation a dynamic, quantitative basis. Considerable modelling work has already been done on the productive capacity of lands with a long history of agricultural use. As methodological work advances, the models developed become ever better equipped to deal with more complex situations such as exist in newly reclaimed lands and in (sloping) areas where erosion is a potential danger. In the second stage of a 'two stage land evaluation procedure', the productivity analysis can then be complemented with a socio-economic analysis in order to decide whether what is technically feasible is also economically attractive and socially acceptable. In the past, the Framework for Land Evaluation (FAO, 1976) has helped enormously to structure our thinking on the most desirable procedure of land evaluation. The principles, definitions and concepts put forward in the Framework will be equally useful in quantitative land evaluation. Land qualities, in particular are pivotal in the process of integrating soil loss (and associated conservation needs) into the land productivity analysis. A possible strategy for this integration will be outlined in the following.

2.2 Integrated erosion analysis

Erosion modifies the productive capacity of land. If the seriousness of erosion, and therewith the need for conservation measures, is to be made explicit, the initial productive capacity of a land-use system (Beek, 1978) must be known as well as the effect of erosion on this productive capacity. Consider the following train of thought:

1. Land productivity is described at the level of the land-use system, (LUS) i.e. as a function of both the land use (type) and the land (unit).
2. Erosion, quantified as soil loss over time, is described as a function of the properties and dynamics of the LUS
3. Conservation needs are (described as) sets of measures which curb or correct erosion-induced modifications of land characteristics and qualities to such extent that LUS-productivity is maintained at an acceptable level.

2.3 LUS; productivity

It was said before that the principles, definitions and concepts put forward in the Framework for Land Evaluation are also useful to quantitative land evaluation. Implicitly, this holds also for the LUS-productivity assessment – which is part of the land evaluation procedure – but considerations of a practical nature force us to use some Framework concepts in a somewhat unconventional way. In particular, this pertains to the treatment of present or projected land use. A 'Land-Use Type' (LUT) is described by a number of 'key attributes' which reflect those biological, socio-economic, technical, etc. aspects of the production environment that are relevant to the productive capacity of the LUS. It is as yet not well possible to handle many key attributes simultaneously in a dynamic way. Therefore, crop selection is taken as the main attribute which characterizes land use. The other key attributes are simply compared with fixed boundary values to judge the scope for land management measures. If, for instance, the availability of farm power and implements is low, then it is unrealistic to consider high technology measures such as sprinkler irrigation. It follows that the dynamic LUS-productivity analysis is done for a combination of one Land Unit (characterized by a set of basic land characteristics) and one crop ('commodity'). This analysis forms the nucleus of a quantitative land evaluation exercise. The combination of one Land Unit, one commodity and a fixed set of management boundaries represents a single land-use system. Multiple systems, i.e. more than one crop on the same field at the same time, can be handled by combining single LUS-analyses, taking into account the effects exerted on the crops by each other (competition for light, water, nutrients, etc.). Compound systems are created as concentrations of single and/or multiple systems. The productive capacity of a Farming System is analyzed – in line with the philosophy of the Framework – by considering combinations of individual LUS-productivity analyses.

It is perhaps useful to stress here that the quality deliberations made earlier with regard to erosion descriptions apply also to the LUS-productivity analysis with which the erosion analysis is to be connected. There are striking parallelisms between the practical difficulties encountered in the construction of erosion models and those met when describing LUS-performance. Not surprisingly, the solutions which have been proposed in terms of regression-based 'simple models' have a familiar appearance. Such models predict productivity, in absolute or relative terms, on the basis of a limited number of land characteristics and qualities that are hidden in black boxes and interact in a linear multiplicative or additive way. Weighting or calibration factors are added to provide couleur locale and an attractive regression coefficient. Last but not least, 'simple' productivity models have in common with 'simple' erosion models that their indiscriminate use in regions other than those for which they were developed leads to gross inaccuracies and misinterpretations. A realistic and universally applicable LUS-productivity model cannot be simple. It can, perhaps, be a simplified version of a comprehensive model. In any case, it must – commensurate with the amount of detail and accuracy pursued by the user – contain more or less elaborate, dynamic descriptions of relevant land qualities and account for their direct and indirect effects on LUS-productivity.

2.4 LUS-properties and erosion

For a static description of land, one refers to its observable characteristics. Such characteristics can be single or compound. Examples of single land characteristics are average total rainfall, slope, soil depth, etc. Compound land characteristics are combined/

intertwined single characteristics; examples are the moisture holding capacity or the saturated hydraulic conductivity of the soil. Of course, land characteristics influence the dynamic behaviour of a LUS, but not necessarily all land characteristics do so in a certain LUS and not all work in the same way. It is therefore attractive to aggregate (the workings of) those land characteristics which, together, cover a basic requirement of land use and thus influence LUS-productivity more or less independent of other land characteristics or aggregations of land characteristics. Counter to the opinion of some Framework exegetes, I consider such dynamic clusters of interacting land characteristics as land qualities. An example of such a land quality would be the quality 'moisture supply to a crop', influenced by single land characteristics such as rainfall and potential evapotranspiration, and compound land characteristics such as the soil moisture capacity, and by interactions between them.

Many of the land qualities that have a direct bearing on LUS-performance are also relevant in erosion analyses. Consider aain the land quality 'water availability to a crop'. In crop production models this quality is described by quantifying water supply to and losses from the root zone during short time intervals with assumed steady state conditions. When the analysis of one time interval is completed, both exogenous and endogenous LUS-characteristics are adjusted to represent the state of the system over the next time interval. The procedure is repeated for so many intervals as the crop cycle(s) contain. Estimates of excess surface water supply over time are generated in the process and present a quantitative and dynamic description of surface storage and runoff. There are similar links between the descriptions of rainfall distribution/ intensity and of physical soil properties in het LUS-productivity analysis and the quantification of kinetic rainfall energy and soil (structure) stability as needed for the analysis of soil detachment and splash erosion. In other words not only can the description of soil erosion be hinged into the LUS-productivity analysis but there can even be complete integration of the two.

2.5 Erosion and the need for conservation measures

The quantification of soil loss in the context of dynamic LUS-behaviour is a first and indispensable step towards sound soil conservation. Whether erosion control measures are actually taken depends not only on the rate and quantity of soil loss but is also policy-determined. One could, for instance, ignore the soil loss altogether, or – the other extreme – strive for zero loss. More commonly, a 'tolerable soil loss' boundary is set, e.g. lower than or equal to the new formation of soil trough pedogenesis. It is doubtful whether a quantity criterion alone can in practice be satisfactory. Surface soil lost through erosion has normally higher nutrient and organic matter contents and better physical properties than subsoil material. LUS-productivity is, in a way, an indicator of the compounded agricultural quality of land. Consequently, 'tolerable soil loss' is often expressed as the soil loss which is associated with a certain drop in LUS-productivity over a certain period of time. The actual values of the acceptable drop in productivity and of a realistic planning horizon are subjects of continuing debate. We best leave these issues to Policy Makers and (Land Use) Planners whose possible motives will not be discussed in any detail here as they are partly of a sociological, economic, cultural and/or political nature and placed outside the scope of this presentation. Let us regard the 'tolerable productivity loss' – boundary as an exogenous datum although we are aware that we have here stumbled upon one of the several points of contact that exist between the first (physical) stage and the second (non-physical) stage of the land evaluation procedure, a point where both stages could interact in an iterative Farming Systems analysis.

The use of a boundary value for tolerable drop in LUS-productivity implies that control measures are not so much regarded as means to reduce soil loss but first and foremost as means to preserve an acceptable level of LUS-productivity over a defined period of time. If control measures are also taken on other grounds, e.g. to protect infrastructure, a tolerable soil loss limit can be set exogenously in addition to the LUS productivity loss boundary. Both boundary values have then to be observed in the analysis. We shall disregard this possibility in this discussion and concentrate our attention on the quantification of the relation between erosion control and LUS-productivity.

2.6 Conservation measures affect LUS-characteristics

In this section, the loop 'LUS-characteristics → erosion → control measures → LUS-characteristics' is closed and therewith the feedback is established that is necessary to keep a generated need for conservation measures within realistic proportions. Conservation measures can affect any of the two components of a LUS: they can affect the use (type) and also the land (unit). It is not possible to give here an exhaustive inventor of imaginable erosion control measures and their effects on LUS-dynamics but the following example may be illustrative:

A measure which manipulates land use could be an increased use of fertilizers. The resulting higher uptake of nutrients induces more luxuriant lea row over time, quantified in the LUS-productivity analysis. This increases the interception of rain drops and decreases the soil detachment/splash erosion figures generated in the erosion analysis. As a consequence, inherent soil fertility is preserved which, in turn, reduces the fertilizer requirements (the quenching effect of the feedback) needed to maintain the minimum LUS-productivity.

Measures which alter land (unit) characteristics and qualities have often a more permanent character than measures affecting land use. Feedback effects may then not immediately be recognized as such but are certainly in operation. For instance, land levelling performed once makes levelling an irrelevant control measure for a large number of years.

2.7 The role of land characteristics/qualities

In the LUS-productivity analysis, the momentary sufficiency of a quality is judged against the momentary requirement of the land use-type/commodity with regard to that quality. Consequently, the analysis consists essentially of a repeated comparison of dynamic commodity requirements and dynamic land qualities. The land characteristics are basic data which are input in the requirement and quality descriptions.

The importance of accurate and reliable basic data cannot be overemphasized: the quality of the analysis results can never surpass the quality of the basic data on which the analysis is founded. The analysis itself does not add any new information on LUS-productivity, erosion hazards or the effects of conservation measures. It solely makes the consequences of the analyst's basic data selection visible. Poor, i.e. incomplete and/or inaccurate, basic data give poor evaluation results, a rule which applies equally to quantitative and qualitative evaluations. There is definitely a need for more efficient collection, more rigid screening and more accessible storage/management of basic information on land and its use. The means to meet this need become increasingly available: data collection, e.g. remote sensing, and handling techniques become more and more sophisticated, computer (memory) princes have nosedived over the past years and awareness of the possibilities of mechanized data handling has increased. As a result, data banks and soil/geo-information systems are now being developed by (conglomerations of) research institutions with foresight. The recent initiation of ISRIC, the International Soil Reference and Information Centre in Wageningen, is a significant step in the right direction.

Better data availability makes the development of better data interpretation procedures a realistic undertaking. An example is the dynamic LUS-productivity model developed by the Centre for World Food Studies in Wageningen (Van Keulen and Wolf, 1985). This model was intended to be the spine of a quantitative land evaluation procedure from the moment of its conception and is set up in such a way that maximum benefit is obtained from the basic data and experimental results published by agronomic research (institutes). The Centres LUS-productivity model consists basically of a string of submodels, each evaluating the influence of one land quality on LUS-performance. The individual submodels are arranged in a hierarchical following order. Their inner structure will not be discussed here but the philosophy of dynamic LUS-modelling and the role of land quality descriptions in the analysis procedure deserve attention. Consider the following arrangement:

	LUS-productivity analysis	
	Land Quality Descriptions:	Commodity Requirement Descriptions:
1st (highest) level	Availability of Solar Irradiance	↔ Energy Requirement (+ temperature range)
↓		
2nd level	Availability of Water	↔ Max. Transpiration Rate
↓		
3rd level	Availability of Nutrients	↔ Minimum Nutrient Concentration of Tissue
↓		
4th level	'Another Land Quality'	↔ Corresponding Requirements
↓		
5th level	etc.	
↓		
etc.		

At the highest level of the LUS-productivity analysis it is assumed that all lower level land qualities satisfy the related commodity requirements. LUS-productivity is then limited by the availability of solar irradiance only (within the capacity of the photosynthetic mechanism of the crop at the prevailing temperature). The calculated productivity is the highest that can be obtained in practice. At the second hierarchical level in the analysis procedure, actual soil moisture availability is compared with the crop's water requirement. The availability of nutrients (3rd level) is still assumed optimal. If soil moisture availability is suboptimal, this affects LUS-productivity. The calculated productivity is then lower than the value established for level 1. At which level the LUS-productivity analysis is done depends on the user. The more land qualities are included in the analysis, the higher the data requirement is, but the closer the resemblance between simulated LUS-productivity and actual (measured) LUS-performance. The analysis is done for short (typically 1 day) time intervals and repeated for the duration of the crop cycle(s) under investigation. Interactions among quality-requirement combinations positioned at different hierarchical levels is achieved through endogenous variable adjustment at the end of the calculations for each interval. For instance, crop growth during a given interval modifies the capacity to intercept solar irradiance (1st level), and the capacity to transpire (2nd level), and the nutrient requirement (3nd level), etc. during the next interval. Similarly, the effect of exogenous 'forcing' variables such as rainfall or fertilizer inputs, is felt at all levels considered in the LUS-productivity analysis.

It will need no further argumentation that the dynamic description of land qualities is a vital part of realistic LUS-productivity assessment. It will also be clear that such descriptions allow to integrate soil loss analysis in the land evaluation procedure and to assess quantitatively the effect of conservation measures on land qualities and thus on LUS-productivity.

2.8 Some additional remarks

What has been said in the foregoing may inadvertently have given the impression that land evaluation is not to be taken seriously unless it is computerized and free of artistic ad hoc deliberations that are founded on something as vague as 'experience'. That notion is definitely wrong. It was merely argued that mechanized data interpretation has – under conditions that permit its use – the advantages of procedural consistency and a quantitative basis. Consistency of procedure is a practical necessity; blind reliance on it is dangerous. Our German friends with their record for procedural thoroughness say it with clarity: 'Jede Konsequenz führt zum Teufel'. Simulation model results mean nothing unless examined and approved by the land evaluator. No matter how sophisticated a mechanized interpretation procedure may be, it is never a substitute for experience.

What has been said in the foregoing was meant to illustrate the importance of land characteristics and land qualities for erosion and conservation analyses. I have placed this discussion within the wider frame of quantitative land evaluation but it was never my intention to suggest a ready-to-use recipe for 'QLE'. The pathway shown may have its merits but it is sadly incomplete; such vital aspects as regionalization of the analysis, reconciliation of the physical boundaries recognized in LUS-productivity analysis and the policy, cultural, etc. boundaries relevant to socio-economic analysis, description and possible substitution of physical inputs and/or labour needs, and many more, remained undiscussed.

What has been said in the foregoing shows that there is no fundamental discrepancy between our past attainments with regard to land evaluation methodology and QLE. On the contrary, Framework concepts and definitions are fully applicable. The results of mechanized interpretation procedures may not strike any land evaluators as impressive yet. Allegorically, I may perhaps refer to the many people who, in the early days of motorization, saw no future for motorcars because the first models were easily outrun by the horse. They have later revised their opinion. The inherent possibilities of mechanized data interpretation are such that a similar development may be expected here. In the future, experience in computerized data management and interpretation procedures will be asked in addition to a record of proven field experience. That development has been set in motion. We cannot close our eyes to it.

References

Beek, K.J., 1978 Land Evaluation for Agricultural Development. ILRI Publication 23, Wageningen; pp 333.

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Van Keulen, H. and J. Wolf (Eds), 1985. Modelling of Agricultural Production: Weather, Soils and Crops. Simulation Monograph Series, Pudoc, Wageningen (in press).

Summary discussion

Burrough: The propagation of errors must be considered when we speak of input; the resulting error may be larger than the individual one when we for example think of the parameters used in USLE.
Driessen: True

Bennema: What kind of data are being put in and what are the assumptions about the input; what kind of meaning does the quantitative data base has; erosion is a permanent process, the loss of soil productivity can be calculated for 5, 10 or 15 years; the time period taken for the study is very important as losses may increase the longer the process, continues.
Driessen: No time horizon is mentioned nor set, but it certainly will take some time to develop methodology, we are not even sure how this problem can be solved,

Flach: The accumulation of errors is also an advantage in finding the errors in the model; thus run the model and see if impossible values are obtained,
Driessen: True, if you want to see if there are any fish in the pond you have to try to catch them.