Nomenclature for Hydrogeological Instability Risks

Subjects: Area Studies
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The nomenclature for hydrogeological instability risks includes four main risks, which are distinguished according to the risk causes :

1) hydrogeological risk, that is slowly caused by natural factors (e.g. collapse landslides in a calcareous cliff in uninhabited areas and erosion along a marly-calcareous slope) in environments where human activities are minimal, i.e. woods, forests and mountain pastures;

2) hydraulic-pedological farming risk, that implies the occurrence of landslides in every winter and is caused by incorrect crop selection, not suitable for the soil and climate parameters (e.g. on a hilly slope with a clay vertisol type with a landslide having different fronts, when the arable land is cultivated with a cereal-legume crop rotation), or the presence of springs with missing drainage in clay soils with a high gradient;
3) hydraulic-infrastructural risk, that is caused by the building up of infrastructures not suitable for the surrounding environment, as they change the downflow of shallow water;

4) hydraulic-infrastructural-pedological-management risk, that is caused by crop operations not suitable for soil and crop parameters, where the selected cultivated plant species are suitable for the environment and field improvements change water downflow (e.g. in soils along hilly calcarenite slopes cultivated with olive orchards, where up-down soil tillage causes shallow water erosion).

Keywords: soil management ; sustainable development ; environmental sustainability ; Soil Cadastre ; best practices ; agricultural mechanisation

1. Introduction

Sustainable development is implemented when the use of resources, e.g. soil, water [1] and air, as well as economic investments, technological innovations and territorial policies satisfy the current and future needs of people [2]. Sustainable development is one of the main objectives aimed at remediating the damages and degradation of urban and suburban territories inflicted during the last five decades.

Both farmers and livestock breeders play a key role in environmentally sustainable soil use and crop management, as their actions can affect the health of the ecosystem where they work, the preservation of the essential services of the ecosystem itself, and the archaeological heritage [3][4].

In fact, it is paramount to preserve the soil–water–plant balance in ecosystems, in order to prevent their degradation [5]. Therefore, modern farmers must know the environmental parameters, in order to rationally work to preserve the balances of the soil commodities for future generations. Otherwise, unsustainable land and crop management could lead to environmental damages.
Hydrogeological instability is widespread in Sicily, in other regions of Italy and other countries, and it is often caused by unethical and unsustainable human activities.

Unfortunately, the current Soil Cadastre is not a model of soil inventory for environmental, social, economic and taxation purposes in a globalised market, such as the model proposed by Raimondi [4]. This innovative Soil Cadastre is aimed at environmental protection and sustainable soil use: a farm owner who implements sustainable crop management and soil use in their fields could be awarded an allowance as a prize.

Therefore, the aim of this encyclopedia key is, within the previously proposed Soil Cadastre, to outline three case studies of three different types of hydrogeological instability risks, in order to propose a nomenclature for these risks, together with the best practices of soil management for each type.

2. Theorethical Background on Soil Cadastre for Environmental Protection

Some scientists characterised soil resources from all over the world [6][7], and used methods for estimating some pedogenesis processes to determine soil age [8]. These researchers characterised newly discovered, expandable minerals (influencing soil fertility) [9], soil organic matter and carbon sequestration in the soil itself [10][11][12][13][14], using an online method to add the soil information in Soil Cadastre, useful for both soil use planners and field managers [15]. As soil information includes within-field, spatially variable crop and soil parameters, sensors for measuring these parameters, GNSS (Global Navigation Satellite System, e.g. GPS, GLONASS and EGNOS) mobile receivers and GIS (Geographic Information System) software are needed for mapping them [16][17][18].

Moreover, the farmers must know the spatial variability of within-field crop and soil parameters, by means of specific sensors and GNSS (Global Navigation Satellite Systems) receivers [19] or remote sensing, in order to produce soil maps by means of GIS software.
In this regard, they need to know the best mechanised agricultural practices for soil conservation, e.g. minimum and zero soil tillage [20][21][22][23][24].

Soil surveys are fundamental for optimising crop operations, in order to preserve soil fertility and yield. A land evaluation provides field owners or managers with the optimal potential soil uses, preventing or remediating soil degradation [25], as well as the possible agronomic improvements and eventual negative effects [26]. In this regard, experienced farmers can transform some limiting soil parameters, e.g. salinity, in specific soil uses, e.g. the cultivation of Nero d'Avola vine cultivar for high-quality wine production [27].

The previously proposed Soil Cadastre is an instrument mainly aimed at promoting sustainable soil uses, as well as their management and CAP (Common Agricultural Policy), in order to reduce environmental impacts [4][15][28][29]. Within this Soil Cadastre, the detailed information included in the Soil Cadastral Certificate allows agronomists and farmers to immediately evaluate sustainable soil uses, by means of land capability, in order to maintain soil productivity and satisfy the needs of the present and future local communities.

The suburban Soil Cadastre implies a renovation of the Soil Cadastral Certificate: other information, i.e. territorial and environmental parameters, as well as soil use, are included in this certificate [4].

If the previously proposed Soil Cadastre is implemented, the following principle must be applied: "Who causes damages must remediate them in the shortest time as possible, while who implements sustainable soil uses must be rewarded". A clear and summarised communication to soil owners and managers is needed in order to communicate the principles of sustainability of the previously proposed Soil Cadastre.

3. Hydrogeological Instability

Hydrogeological risk belongs to the four categories of environmental risk, together with weather, volcanic and seismic ones. An environmental risk occurs when a natural event causes significant damages to people and their economics and can be computed by multiplying the danger by the vulnerability of a territory [30]. The danger is the probability that an event occurs with an intensity and size higher or equal to a default limit, while the vulnerability is the degree of sensitivity to an environmental event of determined intensity. Hydrogeological instability was defined by Gisotti [31] as a disease of civilisation: humanity accelerated the speed of natural events that otherwise would be slower, so they became natural disasters caused by humans.

The Mediterranean climate fosters the occurrence of hydrogeological instability, because it is characterised by rainy winters and dry summers. These events almost always occur in mostly clay soils existing along hilly and mountain slopes and, above all, where layers of siliceous sandstones are alternated with marls or clays when rains of high intensity happen over a short period. These events are more intense if an appropriate soil reclamation is not carried out, a continuous coverage of soil surface is not guaranteed, drainage lines allowing water downflow along slopes are not dug, etc. All territory transformations, building up villages and infrastructures, and unauthorised development, without respecting the environmental limits, become an obstacle to water downflow. Moreover, infrastructures change the permeability of the soil surface by decreasing the infiltration of rainwater and increasing the speed of surface downflow. Hydrogeological instability causes events that can be distinguished in surface erosion, landslides, floods and water stagnation. Surface erosion, caused by water, is the transport of soil mass from the top to the bottom of a slope. The first step of this kind of instability is erosion, which can occur in different ways: layer erosion, rill erosion, gully erosion and, finally, the formation of ravines. A landslide can be defined as deep erosion or mass movement, as it concerns a higher soil thickness. Its main causes are site geology, topography, gradient, overloads due to water, plant presence and growth, human buildings, traffic of vehicles, earthquakes, etc. Additionally, digging out the bottom of the slope carved by rivers and streams, as well as side pushes, e.g. those caused by the swelling of clay soil mass, can cause landslides. The following types of landslides can occur: collapse landslide (free falling down and stockpiling at the bottom); overturning landslide (rotation of a mass around a point below its centre of gravity); rotational slip landslide (movement of the soil mass along the surface); translation slip landslide (same as the previous one but concerning a larger surface); enlargement landslide (surface enlargement through fractures); drainage landslide (continuous deformation of loose materials). Another event of hydrogeological instability is flooding, i.e. “temporary flooding of areas that are not usually covered by water” (Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the Assessment and Management of Flood Risks). The overflow occurs after “a rainy event having exceptional intensity and time, however higher than the average” [31]. The factors influencing surface downflow are: path that water must follow inside the hydrographic basin; gradient; natural or artificial obstacles existing in the hydrographic network; time needed for filling up the existing reservoirs; basin area and shape. During the downflow, solid materials existing in the riverbed are transported via suspension or rolling, according to their weight and size.

These events can cause extensive damage such as the breaking of banks, damage to crop production, infrastructures, dwellings and their inhabitants, as well as changes in the soil parameters, because of the deposit of the transported materials. Yet, flooding can improve soil fertility, which man can use. Among the types of hydrogeological instability, there is also water stagnation, occurring when the water coming from rains, raising of aquifers or floods submerges the soil by removing its air. This event generally happens in flat soils of any texture, although clay soils are the most sensitive to this.
Moreover, in some cases of hydrogeological instability, when up–down ploughing or contour ploughing by rotating the soil slice downstream is carried out on a hilly field, soil erosion becomes prominent [32][33][34][35][36][37][38][39].
In order to prevent or minimise soil compaction and erosion, many scientists proposed techniques of conservative soil tillage, by using implements different from mouldboard plough [40] e.g. subsoiler [41], rotary tiller and chisel plough [42].

4. Case studies of Hydrogeological Instability

Three case studies were selected in three sites of a hilly area of inland Western Sicily, located in the territory of Corleone (Palermo, Sicily, Italy). These case studies provided the input data needed for obtaining the work results, i.e. the hydrogeological instability risks observed during some surveys, on which the nomenclature proposed for these risks is based.
The excerpt of the Map of Instability n. 19 (Sicilian Region - Territory and Environment Department, Basin Shred Plan for Hydrogeological Layout, 2005) including the above area is shown in **Figure 1**.

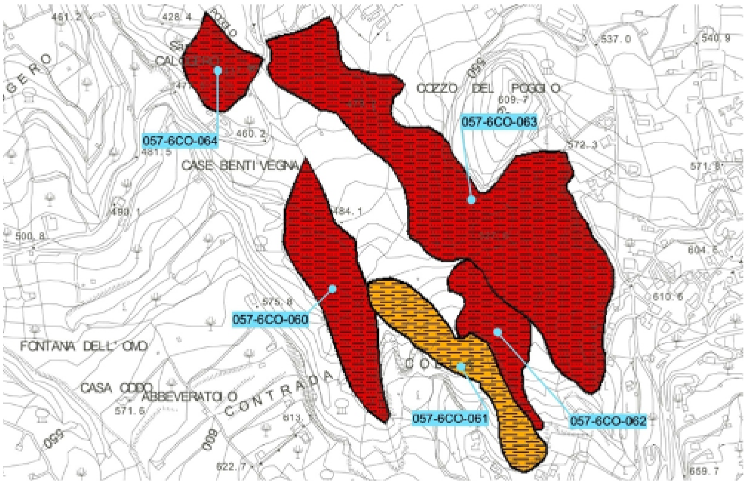

Figure 1. Hydrographic basin of Belice river (057) - excerpt of the Map of Instability n. 19, including the surveyed area: the areas where soil erosion caused landslides are highlighted, i.e. those having active landslides are in red colour, while those having landslides at rest are in yellow colour (Sicilian Region - Territory and Environment Department, Basin Shred Plan for Hydrogeological Layout, 2005).

From March to September 2015, surveys were carried out in this area to identify the human activities that caused hydrogeological instability.

Thus, it was possible to focus on the unethical human activities that reduced the productivity of soils and caused damages to their infrastructures.

The above three case studies were selected for the surveys, as they are characterised by three different types of hydraulic instability risk:

- at the first site, a landslide was observed on a hilly slope (arable land) cultivated with a cereal and legume (Italian sainfoin) crop rotation;
- at the second site, an area degraded because of flooding, gully erosion and water stagnation was observed;
- at the third site, the damages caused by incorrect crop operations, implemented for an unsustainable field improvement (not suitable for the natural conditions of the hydrographic network), were observed.

The surveyed area is located at an altitude between 500 and 700 m a.s.l.

In this area, soils are mostly clay and calcareous, specifically Vertisols and Inceptisols. Entisols are slightly distributed where floods occur and on tender and hard rocks. The soils generally originate after a long pedogenesis and often have a high depth.

In the surveyed area, it is possible to observe dry arable lands cultivated with cereal and legume crop rotations on clay formations, as well as olive orchards, vineyards, small arable lands and pastures on the roughest soils.

This area is highly sensitive to hydrogeological instability, because of its soil and climate parameters. In fact, some areas subjected to landslides and damages caused by floods and water stagnation were identified during the surveys.

5. Nomenclature Proposed for Hydrogeological Instability Risks

The data and information provided by many authorities are fundamental for implementing appropriate strategies for reducing the hydrogeological risk through correct territory planning, structural interventions, alerting and monitoring tools, as well as territory maintenance and the best agricultural and forestry practices. All of this information should be communicated through the previously proposed Soil Cadastre.
In order to minimise surface erosion, appropriate hydraulic-forestry soil reclamations must be carried out in collection basins. After studying the basin parameters, it is possible to carry out, along the slopes, the transplanting and/or seeding of soils, terracing or building up of cagesor concrete walls or installation of retention nets to prevent rocks from falling down. Instead, the intensive works change the slope and the longitudinal outline of streams, building up thresholds and weirs, walls, gabions or side coverages along the bed, as well as repellents or panels. Moreover, appropriate agronomic techniques must be implemented, such as those described in the Code of Good Agricultural Practice [43].

Furthermore, the danger of landslides needs to be evaluated, preventing these landslides by means of hydraulic-forestry land reclamation, drainage works, the geo-referenced monitoring of crevasses on the soil surface by means of a GNSS receiver [19] and alarms.

According to the EU Floods Directive (Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the Assessment and Management of Flood Risks), the management of flood risk is needed when an unsustainable work exists in a site. Therefore, it must be removed or changed to make it suitable for the site itself, thus minimising flood risk. Hydrological and hydrodynamic simulation tools can monitor rainfall and temperature. Another effective practice can be water canalisation, by building up banks, massive walls and canals, in order to increase the downflow capacity in the bed. Furthermore, expansion cases, artificial flood control channels and diversions can be built up to remove water from the current, even if these works are expensive and have a large environmental impact.

Finally, in order to face water stagnation, drainage works need to be built up, e.g. ditching or the use of pipes and drainage wells.

Based on the observations carried out during the surveys, it was possible to deduce the causes of hydrogeological instability aside from ongoing climate change and human activities, i.e. building up infrastructures to obstruct the downflow of the excessive water and accelerate the degradation process of natural resources, able to minimise soil fertility.

The EU communication COM (2006)231 that addressed the “thematic strategy for soil protection” (Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions-Thematic Strategy for Soil Protection) stated that in Sicily, like elsewhere, threats are caused by incorrect crop operations and unethical agricultural and forestry practices, excessive soil exploitation and the abandonment of rural areas. Therefore, human activities are factors of hydrogeological instability. Thus, sustainable human activities can prevent from hydrogeological instability and farmers must be educated and become aware of these activities, as well as addressed to the principles of Soil Cadastre, only if their management is harmful to the environment. Moreover, farmers are increasingly aware of acting with maximum safety by reducing, for instance, tractor overturning risks in hilly areas and, thus, work accidents and expenses for medical and hospital care [44].

All the best agricultural practices able to protect soil structure will be promoted: minimum tillage and zero tillage; permanent soil cover with grass and diversified crop rotations and associations, leaving crop residues in the soil.

These best practices will:

- maintain the active soil layer;

- increase water retention capacity;

- maintain soil organic matter and reduce the emissions of greenhouse gases (GHGs) and the consumption of fuel;

- increase carbon sequestration in the soil and, therefore, reduce the emission of CO2 into the atmosphere.

Therefore, in order to specify the causes of hydrogeological instability due to human activities, a nomenclature is proposed for the instability caused by downflow water. The proposed nomenclature allows brief communications with farmers, reminding them of more sustainable soil management. This nomenclature includes four main risks, which are distinguished according to the risk causes. The first risk occurs in environments where human activities are minimal (i.e. woods, forests and mountain pastures), while the other three risks are caused by incorrect human activities. The structure of this nomenclature proposed for hydrogeological instability is shown in **Table 1**.

Table 1. Nomenclature proposed for hydrogeological instability risks, based on the three surveyed case studies.

Risk Type	Risk Causes
Hydrogeological risk	**Natural factors in woods, forests and mountain pastures.**
Hydraulic-pedological farming risk	**Crop selection (e.g. cereal and legume crop rotations on arable lands) is not suitable for the within-field soil and climate parameters or the presence of springs (hydrological limit) with missing drainage (a surface levelling must be carried out by means of bulldozer in September) in clay soils with a high gradient (pedological limit). Landslides occur every winter.**
Hydraulic-infrastructural risk	**Building up infrastructures not suitable for the surrounding environment, as they change the downflow of shallow water, for example:** - Reduction in the bed of narrow valleys or rivers for agricultural purposes; - Protection grills of access to road bridges not correctly placed and subsequent blockage of meshes with scrub, which is transported when the river floods by breeching dams and overflowing onto roads and in soils; - Bridges built up for joining the two banks of a narrow valley or river with a canal flow rate not suitable for the maximum flow at that location, causing overflow; - Walls or fences of estates changing the downflow lines; - Driveways upstream blocking water downflow in the adjacent cadastral parcels; - Canalisations changing water downflow.
Hydraulic-infrastructural-pedological-management risk	**This risk occurs where crop operations are not suitable for the soil and climate parameters, e.g. up–down soil tillage along slopes, causing water erosion, are carried out, while the soil use is correct and field improvements change water downflow.**

6. Implementation of the Proposed Nomenclature for Hydrological Instability Risks within Soil Cadastre

The surveys carried out allowed to understand once more that human activities, which are not suitable for certain sites, cause the different types of hydrogeological instability.

The most harmful human activities identified were concerned with building up infrastructures unsuitable for the site, incorrect crop selection and planning of field improvements, and the implemented mechanised crop operations. In fact, in the case of hydraulic-pedological-farming risk, up–down soil ploughing must be replaced by contour ploughing: the plough mouldboard must let the soil slice rotate upstream, in order to compensate for soil erosion, moving it downstream. Another option could be minimum tillage, e.g. by means of a subsoiler [40].

Nowadays, the need to make the field manager aware of their role is paramount, as he has the great responsibility to implement sustainable soil use. In fact, the field manager must select the appropriate agricultural machines and implements needed to carry out the best mechanisation practices.

The nomenclature proposed for hydrological instability risks and the recommendations included in the previously proposed Soil Cadastral Certificate suggest to the field manager the best practices that could be implemented. In fact, in a hydrographic network, the constructions needed to regulate water downflow must be designed by a professional and the downflow lines must be kept without diverting water to another sub-basin. Moreover, the previously proposed Soil Cadastral Certificate is also useful for communicating the reasons for the current unsustainable soil use or management to the field owner or manager. The implementation of these principles educates the farmer and prevents environmental risks, in order to make territories safe without damages to the environment, people and their infrastructures.

Therefore, when hydrogeological instability is caused by human activities, mechanised crop operations, i.e. conservative soil tillage, and the Soil Cadastral Certificate are paramount instruments for implementing environmental sustainability.

In fact, the soils of Sicily, similar to those of other regions of Italy and other countries, are subjected to a high degradation, because of compaction and erosion, often caused by unsustainable human activities.

The effects of water erosion, mainly caused by human activity, are widespread in Sicily and elsewhere.

The nomenclature for hydrogeological risks is proposed in order to guide the field owner or manager towards a sustainable soil use.

This nomenclature aims at summarising hydrogeological risk types that have been well known from a long time. Moreover, this nomenclature can immediately communicate risks, eventually making the soil use or management of some parcels unsustainable to the farmer. Therefore, sustainable soil use and management must be uniformly spread in every cadastral parcel of every territory.

In the future, the proposed list of hydrogeological risk types will be longer, because it will include the risks that are yet to be discovered.

The proposed nomenclature could be used by government bodies, e.g. ministries, regional departments and municipalities, for urban and territorial planning, i.e. for planning actions that aim to prevent or minimise hydrological instability in the relevant urban and suburban territories, according to the risk type existing in each area.

The innovative Soil Cadastre [4] will be a paramount instrument for promoting sustainable soil uses, as it will be able to inform farmers of unsustainable soil uses and management. Moreover, the field owner or manager will receive recommendations on the best mechanisation practices to be performed, i.e. conservative soil tillage, e.g. contour ploughing with upstream soil slice rotation or minimum tillage by means of a subsoiler.

At the same time, the farmers who carry out sustainable activities could be rewarded. If a natural disaster happens, the above Soil Cadastre will quickly and easily allow public interventions to be managed and implemented. Thus, the parcel owner could be provided with a fair allowance without a written application, according to the so-called bureaucratic simplification [28].

This will allow humans to continue adopting a positive approach to the environment, with an increase sensitivity towards ecosystems and an awareness of their vulnerability.

Thus, at the same time, farmers will obtain economic benefits from the sale of the assets produced by the environment, as well as from the management of their fields by means of a prize [4].

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