

## **IPL Project (IPL-260) Annual Report Form**

**Period of activity under report  
from 1 January 2022 to 31 December 2023**

### **1. Project Number and Title:**

**IPL-260 Landslide Risk assessment in the High City of Antananarivo**

### **2. Main Project Fields**

Select the suitable topics. If no suitable one, you may add new field.

(1) Technology Development

B. Hazard Mapping, Vulnerability and Risk Assessment

### **3. Name of Project Leader**

**William Frodella**

Affiliation: UNESCO Chair on prevention and sustainable management of geo-hydrological hazards,  
University of Florence

Via G. la Pira 4, Firenze 50121; Phone: +39 0552757559; Mobile: +39 3407651280; Fax: +39  
0552055317

Core members of the Project: Veronica Tofani/UNESCO Chair on prevention and sustainable management of geo- hydrological hazards, University of Florence; Daniele Spizzichino/The Italian Institute for Environmental Protection and Research–ISPRA, Rome; Claudio Margottini/UNESCO Chair on prevention and sustainable management of geo-hydrological hazards, University of Florence; Francois Cristofoli/RC-Heritage consultants, Tamara Teissedre-Philip/Paris Region Expertise Madagascar – PRX; (Representative of the Région Ile-de-France à Madagascar).

### **4. Objectives (5 lines maximum)**

The focus of the project is to perform a comprehensive landslide risk assessment in the High City of Antananarivo, for both the protection and conservation of the cultural heritage site, and also for suggesting sustainable mitigation measures as a contribution for the site's management plan.

### **5. Study Area**

The UNESCO Core-Buffer zones of the High City of Antananarivo and surrounding natural and urban areas.

### **6. Project Duration**

Three years

## 7. Report

### 1) Progress in the project

The municipality of Antananarivo (capital of Madagascar), in cooperation with Paris Region Expertise Madagascar (PRX), is preparing a Dossier for the inscription of the historical part of the city into the UNESCO World Heritage list. The UNESCO Chair on Prevention and Sustainable Management of Geo-Hydrological Hazards of the University of Florence has contributed to the Dossier by defining how the local geology interacts with the landslide hazards, in order to understand of the triggering factors and to investigate the impacts on both the historical buildings and the houses of the depressed neighborhoods, with the final aim of proposing a general master plan for the mitigation of the geohazards.

The first step of the work has been the geotechnical characterization of the materials forming the high city of Antananarivo (Analamanga hill) that was performed by combining the outcomes of the field surveys, laboratory geotechnical analysis, the interpretation of the geophysical data (geoseismic and geoelectric) and borehole literature data.

The second activity was related to the production of a multitemporal slope-scale landslide inventory from 2015 to 2020, involving the winter 2015 shallow landslides event and other more recent single events. The first outputs consist of 78 shapefile polygons related to the winter 2015 shallow landslide event, with attribute tables also showing location (latitude/longitude of centroid), perimeter, surface/volume, width, crown/toe elevation.

On this basis, an integrated landslide hazard assessment was carried out in the High City of Antananarivo in order to assess the landslide exposure of the town cultural heritage and the interconnecting roadways- pathways. The related hazard of the identified landslide phenomena (shallow landslides, debris flows) was then assessed by means of susceptibility and runout analysis. The shallow landslide susceptibility map (Figure 1) shows that most of the analysed area is affected by moderate to very high landslide susceptibility. The shallow landslides-prone areas (high and very high susceptibility) are located along the Middle Town quarters, particularly at the foot of the central sector of the western hillslope (from north to south: Mahamasina, Ankadilalana, Tzimbazaza quarters), where shallow debris rotational/translational slides involve mainly the eluvial-colluvial and the lateritic deposits. Here the intense linear creek erosion of the soft lateritic soil cover creates large gullies, which are rapidly expanding, as shown by their retreating scarps damage the road pavement, and the presence of several potential slope instabilities in correspondence of the headcut of their apex. The eastern slope is less prone to shallow landslides, except for the middle-southern sector, especially two creek basins: the first is located east of the Rova in the Manjakamiadana quarter, while the second is located east of the Ambohipotsy quarter. The slope north hill sector shows a general stability due to the widespread urban cover and the lower slope angles, except for the area around the tunnel, in the Ambohijatovo quarter. The southern sector shows some potentially unstable areas at the top of the abandoned quarry slope cuts in the Anjahana-Ambohipotsy quarters. The cultural heritage buildings are not located in landslide-prone areas, except for the Trano-Gasy

Houses, which is placed in an unstable area on the top of the western slope, between the Rova and the Andafiavaratra Palace, as testified by the sandbags used to stabilize its upper sector and by the persistent open cracks in the pavement.

The intensity of potential earth-debris flows was assessed using the GPP model, an open-source code working in a SAGA-GIS environment that simulate the run-out and defines which areas are more prone to be impacted by debris flows.

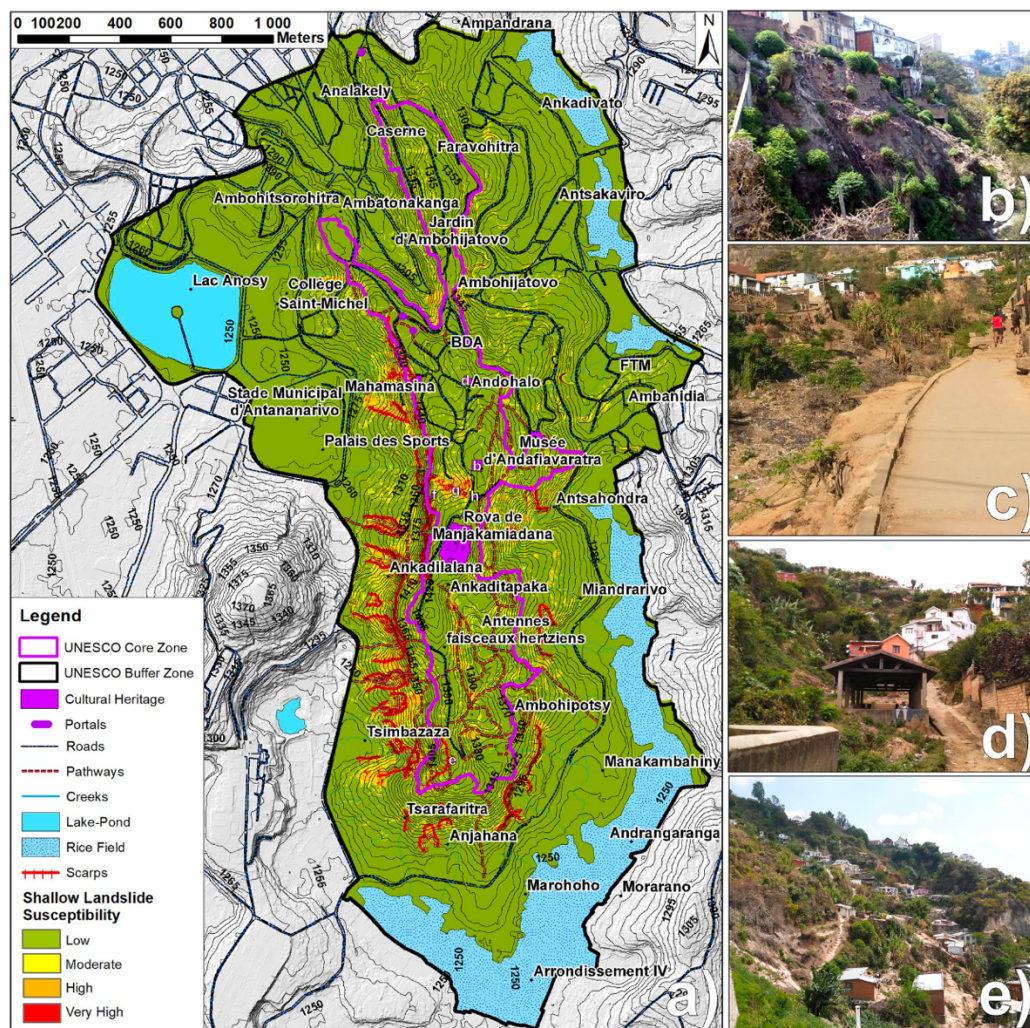


Figure 1: Analamanga hill susceptibility map for shallow landslides. From Frodella et al. (2022)

## 2) Planned future activities or statement of completion of the Project (15 lines maximum)

The future planned activity will be related to the quantitative landslide risk assessment of the high city of Antananarivo. Landslide hazard values that have been already evaluated will be combined with vulnerability and exposure of the elements at risk. Particular attention will be posed to the vulnerability and exposure of cultural heritage buildings.

## 3) Beneficiaries of Project for Science, Education and/or Society (15 lines maximum)

The actors involved in the protection of the High City Cultural Heritage and civil protection activities, such as Paris Region Expertise (PRX) Madagascar, the municipality of Antananarivo and BNGRC (Bureau National de Gestion des Risques et des Catastrophes).

#### 4) Results (15 line maximum, e.g. publications)

The first results of the projects have been published in Landslides journal and in the Open access book P-LRT as well as presented during the Sixth World Landslide Forum (WLF6) in the *Session 1.7: Cultural heritage threatened by landslides: from earth observation and in situ investigation to sustainable mitigation measures*.

##### Publications:

Frodella W, Rosi A, · Spizzichino D., · Nocentini M., · Lombardi ·L., Ciampalini ·A., Vannocci P., · Ramboason N., · Margottini ·C., Tofani V.,· Casagli N. (2022) - Integrated approach for landslide hazard assessment in the High City of Antananarivo, Madagascar (UNESCO tentative site), Landslides journal, 19:2685- 2709

Frodella W., Spizzichino D., Lazzeri G., Margottini C., Tofani V., Casagli N. (2023) Assessing Landslide Hazard in the High City of Antananarivo, Madagascar (UNESCO Tentative Site), Progress in Landslide Research and Technology, Volume 2 Issue 2