

# Environmental impacts on karst in Papua New Guinea

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## Abstract

The extensive tropical karst areas of New Guinea combine rugged relief, large sinking streams and very extensive cave systems. Many of these areas have high conservation significance with largely intact primary rainforest, rich wildlife and virtually no human presence. They are subject to a range of natural and human disturbance processes, including landslides, fires, forest dieback, road construction, logging and induced settlement. The combination of rugged terrain and very difficult access mitigates against conventional monitoring based on specific locations and instrumentation to assess impacts on karst processes and biota. Monitoring environmental impacts in Papua New Guinea (PNG) therefore involves the integration of satellite and aerial imaging techniques with on-ground observations. Current approaches include use of moderate resolution imagery (Landsat, SPOT) to identify areas of change, then high resolution imagery (sub-metre QuickBird, IKONOS, WorldView) to quantify extents and possible causes. This scaling process depends on the identification of areas of concern to initiate more detailed assessments with helicopter, drone and on-ground surveys. There is potential for at least two World Heritage nominations for PNG, but their realisation will require capacity building amongst PNG government staff and novel approaches to management to conform to World Heritage operational guidelines.

## Karsts of Papua New Guinea

The karst areas of Papua New Guinea occupy about 15% of the land area, extending from nearly 4000 m on the Huon Peninsula down to sea level in the Kikori basin. The major rivers draining the central cordillera of New Guinea cut through many limestone areas, which typically form steep parallel ridges with scarps on the southern side and intervening valleys or plateaux. There are extensive alluviated lowland karst plateaux, one of which in the Kikori - Kutubu area has an area of 15,000 km<sup>2</sup>. From west to east along the spine of PNG there are karst areas in the Star Mountains, Hindenburg Plateau, Muller Range, Southern Highlands, Eastern Highlands and Huon Peninsula. The karst plateaux and ranges end abruptly with escarpments from 300 to 750 m high (Francis *et al.*, 1980; Gillieson & Spate, 1998) descending to the

alluvial plains of the Fly and Kikori rivers. Many of these escarpments have large springs emerging at the base of the limestone, and in many cases there are fossil cave passages visible in the cliffs (Gillieson, 1985). The escarpments are prone to frequent rock falls and landslides which may occur on a decadal timescale. The large island of New Britain has extensive karst areas on the south coast with the Nakanai area containing very deep caves and large underground rivers (Audra *et al.*, 2011). The Lelet Plateau of New Ireland has an extensive polygonal karst plateau over an area of 500 km<sup>2</sup> and an altitude range of 1400 m (Gillieson, 1997). Large springs fed from the plateau emerge at the coast. The karst and caves of New Guinea are young and are actively forming under a humid tropical climate, with continuing uplift on active plate margin. The extensive and complex limestone geology with high-angle faulting provides a wide array of expressions of tropical limestone karst morphology. Extensive karst plateau at all elevations are completely covered in polygonal karst terrain with dolines and springs. It is likely that the distribution of individual karst types is more controlled by geology than by altitude or climate. There have been no studies of karst processes in New Guinea to date.

The principal tectonic force for the development of the New Guinea landmass was been the northward drift of the Australian continental plate. Following deposition of Miocene limestones along a slowly subsiding shelf, there was an uplift of the order of 4000m in the Pliocene. This uplift was accompanied by high-angle faulting by which thick sheets of limestone moved to create parallel ridges with quite complex stratigraphy. Uplift was largely complete by the early Pleistocene, but minor movement associated with the Highland volcanoes has since caused some local folding and faulting.

The karst areas of New Guinea have been typically the last lands to be settled in any region. Historically the only uses for the karst areas have been hunting, forest products harvesting and some very minor dispersed settlement. Starting in the 1920s Australian mining companies showed interest in the natural gas and oil seepages in the Southern Highlands, and over the last 30 years there has been extensive exploration, drilling and finally exploitation of very large gas

reserves. A 220km liquid natural gas pipeline has now been constructed from wells in the Southern Highlands to the coast at Kikori. This will provide a significant proportion of the PNG national income for the foreseeable future. Associated with such development is induced settlement, facilitated by

expanding road networks and opportunities for work associated with the development. Thus the karst areas of Papua New Guinea are at a cusp in their history. It remains to be seen whether the Papua New Guinea government will enact effective legislation and management to protect these areas.

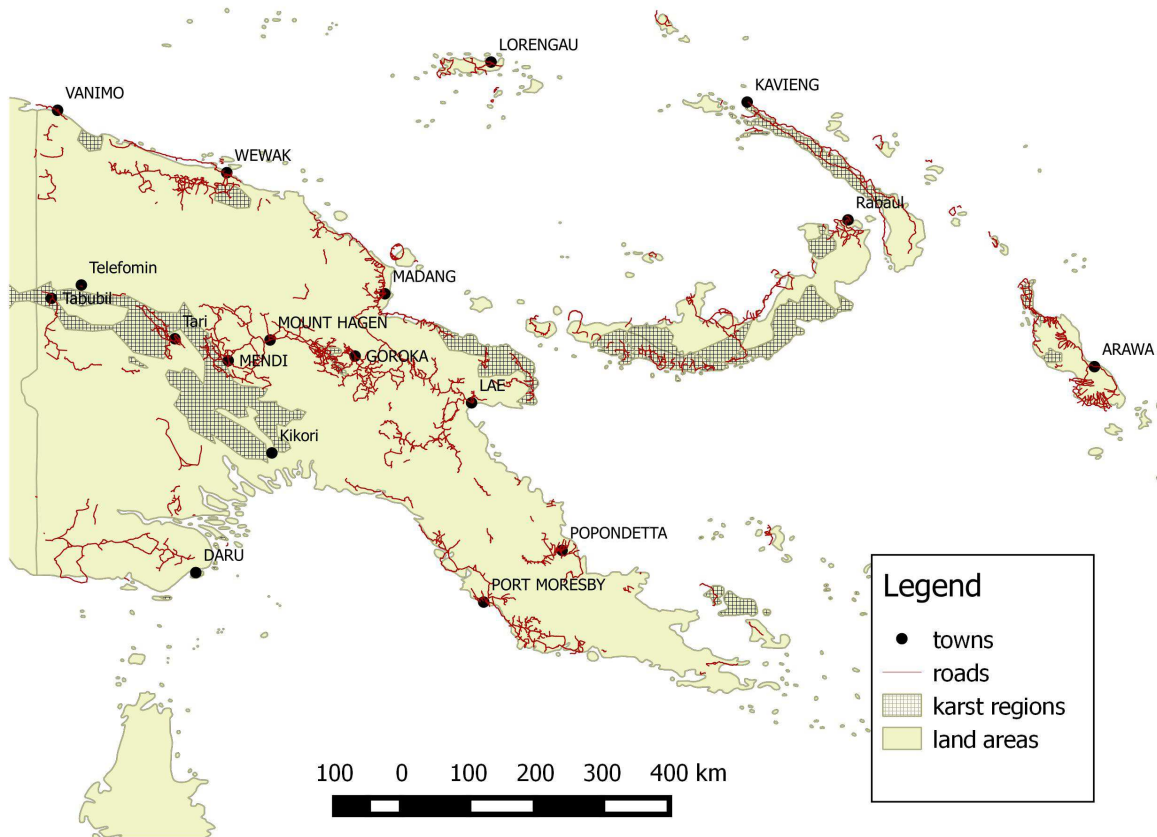


Figure 1: Karst areas of Papua New Guinea. Data from [http://web.env.auckland.ac.nz/our\\_research/karst/#karst6](http://web.env.auckland.ac.nz/our_research/karst/#karst6)

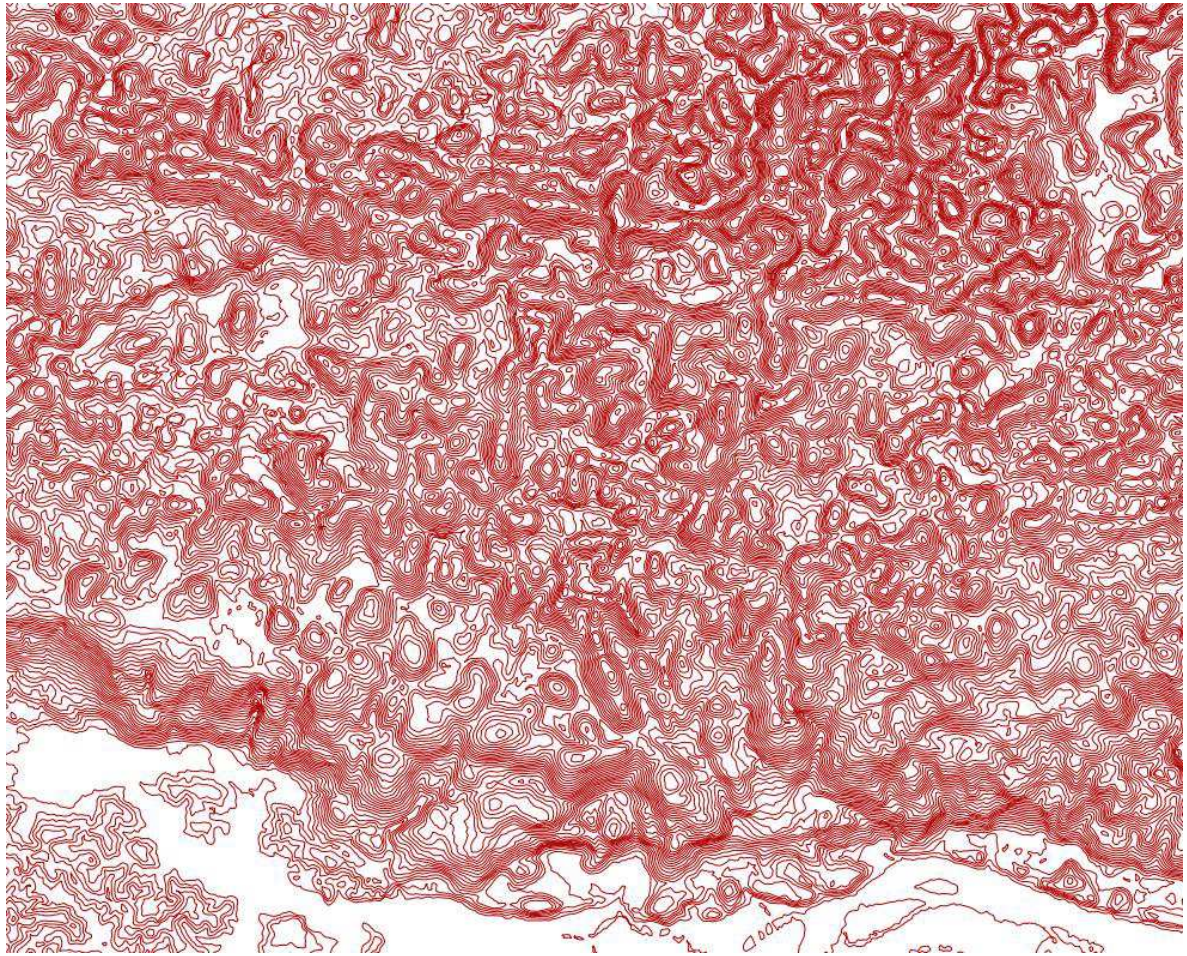


Figure 2: LIDAR derived contours (5m) of polygonal karst terrain to west of Beaver Falls and north of the Hegigio River, in the Kikori region.



Figure 3: View of polygonal karst terrain from Figure 2, looking northwest from the Hegigio River

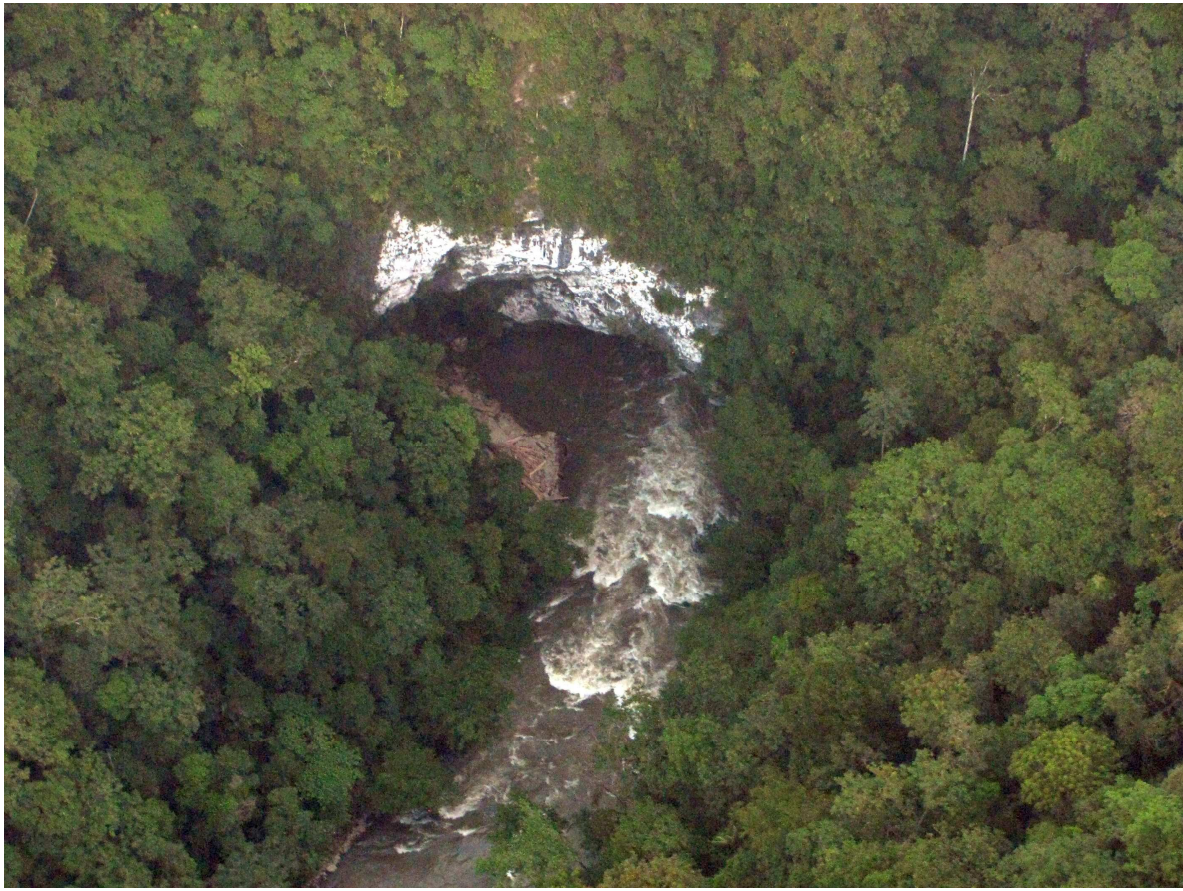


Figure 4: Unnamed stream sink in the Baia River area, Karius Range, Southern Highlands

### Environmental impacts on PNG karsts

Small disturbances of less than one hectare are common in PNG rainforests. The disturbances may be from natural causes such as insect damage, plant disease, natural tree death, wind throw from storms, drought, frost or lightning strikes. Human induced disturbance at this scale includes forest clearance for food gardens, selective logging or fires lit by people. Canopy gaps indirectly cause the redistribution of water and nutrients and affect the dynamics of plant and animal populations. Seedlings and saplings grow to fill the gap within 6 months, and the forest species composition may change over time as a result of this continuous low-level disturbance.

Large disturbances occur on a greater spatial scale, affecting large areas of forest ranging from many hectares to square kilometres. Such disturbances may include natural events such as landslides, volcanic mud flows, floods, fire, frost and drought, or they may be human in origin such as fires, forest clearing, road building, and invasion of weeds. Regeneration of affected areas is successional and the regrowth may be similar or different to existing vegetation.

Landslides are widespread in PNG as a result of the combination of steep terrain, heavy rainfall and seismic activity. 'Landslide' is a generic term for a range of mass movement processes including rockslides on steep escarpments, rotational slumps and bank collapses in deep soils and unconsolidated materials, and mudflows along valleys. All of these processes can be identified in satellite imagery and may be visible for decades. In PNG, landslides are usually triggered by earthquakes or intense rain storms. Tectonic instability and the extreme ruggedness of the terrain make the highlands very susceptible to landsliding, but the extent to which regional factors influence the distribution and severity of landsliding is uncertain. Rockslides are common on the limestone escarpments and ridges that characterise the Southern Highlands. They vary in size from 50-100m wide and 200-600m high (Gillieson and Spate, 1998). Landslides are common along the limestone escarpments of the project area and their debris form broad aprons below the scarps. Along many rivers bank collapse is a common process caused by undercutting of unconsolidated sediments by channel migration. Many valleys have been infilled by mudflow deposits which are also prone to these

collapses. All of these can be regarded as natural processes operating on decadal timescales. Hydrologic change caused by infrastructure (for example, concentration of flow through road culverts leading to downstream bank erosion) may accelerate bank collapse or sedimentation, including within caves (James, 1993).

Natural and human disturbance types on karst are specifically:

- tree fall gaps and forest dieback
- induced settlement and associated shifting cultivation
- fires
- landslides and mudflows
- roads and associated infrastructure

- logging

Patches of tree death or canopy gaps may be detected in aerial photographs of an area. Such patches are often attributed to *Phytophthora* pathogens. Of these, the species *Phytophthora cinnamomi* is the most widely distributed and the most widely known as causing root rot disease and death in a large number of plant species. It is believed that *P. cinnamomi* originated near Papua New Guinea and it has also been detected throughout forests in Australia and Asia, and in other parts of the world (Arentz and Simpson, 1986). The pathogen favours mild temperatures, areas of high rainfall (greater than 600mm per annum), and waterlogged soils. It is known to survive for as long as six years in moist soil.



Figure 5: *Nothofagus* dieback on polygonal karst in the Homa region, probably due to *Phytophthora cinnamomi*.

In PNG fire may occur naturally as a result of lightning strikes or it may result from human ignition. Lightning strikes are usually associated with heavy rainfall and rarely lead to forest fires. Fires in tropical forests are most likely to occur in times of severe drought associated with the El Niño Southern Oscillation (ENSO), when moisture levels are low. Meteorological records indicate that severe droughts occurred in PNG in 1896, 1902, 1914, 1982 and 1997.

The Southern Oscillation Index (SOI), a measure of the probability of occurrence of good rainfall, was strongly negative for each of these years. Records show that extensive fires were observed in PNG in association with many of these droughts. For example, the 1997-1998 ENSO in PNG was characterised by reduced rainfall and reduced cloud cover, resulting in severe drought and frosts above 2200m in the Western Highlands. Extensive fires

occurred, many of which were started by landowners intending to clear land, or by people who believed that the smoke would produce rain (Allen, 2000).

Road building associated with logging and infrastructure construction provides access to previously remote and inaccessible areas. Roads also play a major role in opening up new areas to exploitation by hunters, miners and illegal loggers (Laurance *et al.*, 2009). Roads can cause erosion, contribute to wildlife mortality, provide pathways for invasion by exotic species and pathogens, and contribute to loss of biodiversity habitat and long term forest disturbance. In addition, other linear infrastructure such as pipelines and powerlines has also been found to have significant effects on natural ecosystems, particularly in tropical environments. In many instances, such linear infrastructure can create barriers to species that avoid living in or traversing forest edges, and after heavy tropical downpours, silted run-off from infrastructure projects can affect local aquatic ecosystems.

While regulations do exist to control logging, lack of resources means that compliance checks are rarely undertaken. High levels of corruption and unsustainability in the forestry industry have created

significant negative social upheaval in villages, with many overseas logging companies ‘mining’ PNG forests. Rates of forest loss can be up to 5% per year, amongst the highest in the tropical world. Widespread environmental damage from logging in PNG (Saulei, 1984) includes:

- Damage to stream and marine ecosystems from soil erosion, sediment and nutrient run-off
- Loss of biodiversity due to habitat destruction and hunting
- Forest fragmentation (Figure 6)
- Forest conversion to grasslands that may increase the likelihood of fires
- Damage to forest food sources such as sago palms
- The creation of waterlogged or swampy environments with acidic soil

The rugged and mountainous nature of PNG has meant that most of the country’s timber extraction is confined to the more accessible coastal lowlands and offshore islands (Shearman *et al.*, 2009). Illegal logging is widespread in lowland areas, and this activity is now encroaching on karst areas in the Kikori River basin.



Figure 6: Logging on lowland forest in the Kikori Basin, access road typically leads from a riparian wharf into the forest. No rehabilitation of logging roads is carried out.

## Monitoring disturbance using multi-level remote sensing

The extensive karsts of Papua New Guinea are thus subject to a range of environmental impacts. Monitoring this disturbance is problematic given the difficulty of accessing many areas on the ground. The only practical way of monitoring either natural or human-induced disturbance is to adopt a hierarchy of monitoring approaches, combining satellite remote sensing with aerial survey and imaging and lastly on-ground inspections. It can be carried out using moderate resolution satellite imagery such as Landsat and SPOT at annual intervals. Areas of interest can be identified using change detection techniques. If identified areas warrant further investigation then high resolution imagery can be used, for example Rapid Eye or Ikonos or World View with spatial resolution between one and 5m. Further investigation can use helicopter survey or drones to collect specific information. Security issues may impede or negate on-

ground surveys. Thus the concept is to have scaling of investigations from coarse to high resolution imagery, triggered by thresholds of interest.

For example induced settlement might be detected as areas of cleared rainforest on Landsat imagery. If this were close to new roads then high-resolution imagery would be obtained to quantify the exact extent of the settlement and number of houses. Finally helicopter survey, perhaps coupled with a site visit, would allow identification of the people involved and their rights to the land being settled. Another example is the detection of logging adjacent to an area of karst in the lowland area. Logging roads show up clearly on Landsat imagery but the individual snigging or extraction tracks are more clearly seen in high-resolution imagery. Cable logging is also being used but will only show up in high-resolution imagery. These assessments may trigger a site visit using helicopters to interview the logging contractors.

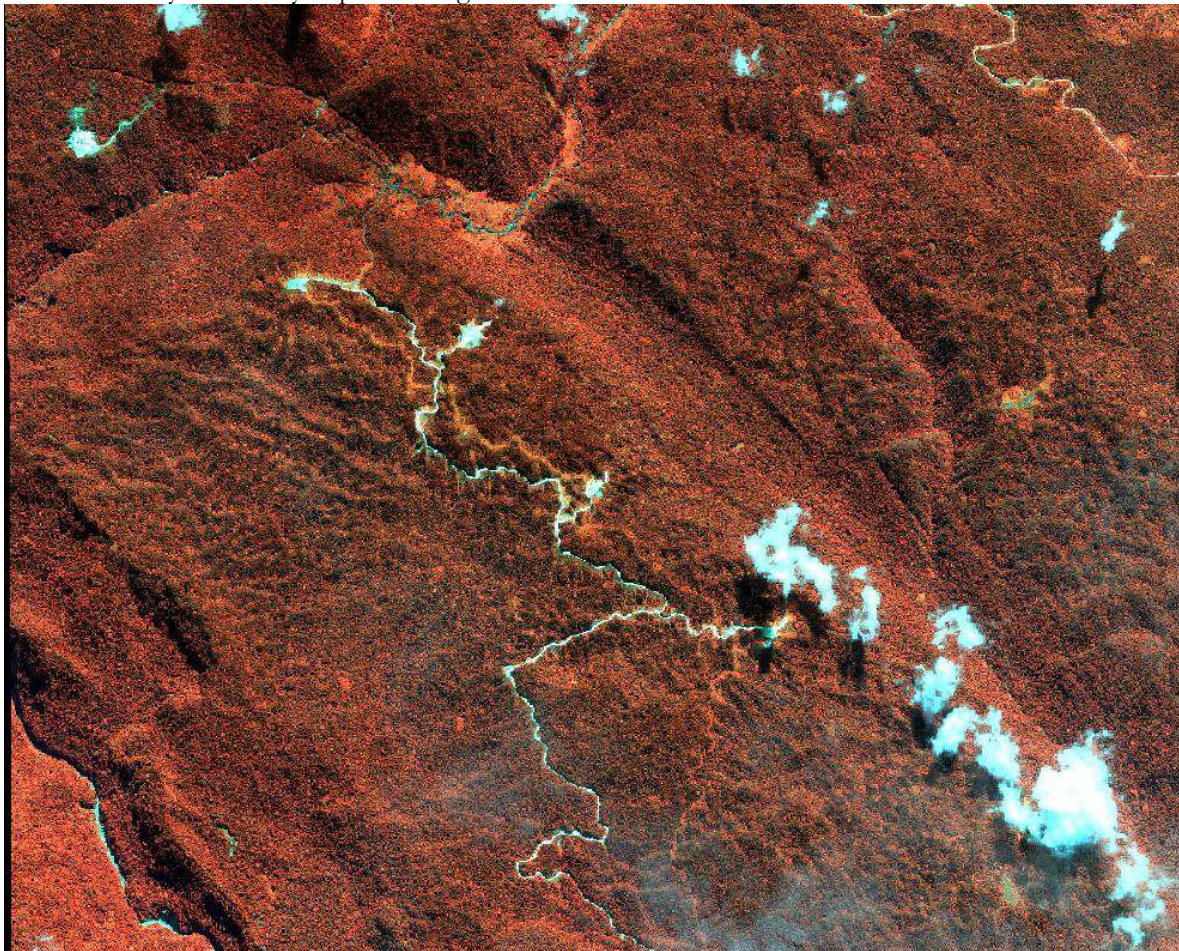


Figure 7: IKONOS near infra-red image of the Hides Ridge area, showing gas wells on polygonal karst. Image resolution is 4m.

The areas affected and the length of logging roads in an area can be quantified by importing the imagery into GIS and using on-screen digitizing techniques to

map out the features of interest. Tables of areas of impacts in a project area provide a good evidence base for monitoring change. If imagery is obtained on

an annual basis then it is possible to identify areas of new natural disturbance, for example landslides or fires and expanded areas of induced settlement or logging. The availability of high resolution satellite imagery at almost daily intervals makes it possible to map and monitor rapidly changing impacts such as wildfires and floods. New sensors are being launched with a swarm of smaller satellites, each of which image a given area on the earth's surface twice a day, and largely solve problems of cloud cover. High resolution radar imaging penetrates cloud and allows monitoring of persistently clouded areas, but is expensive when repeat monitoring is required.

### World Heritage nomination of PNG karst areas

A study by Williams (2008) showed that World Heritage karst sites are globally reasonably well distributed with the exception of arctic and glacial environments. A number of humid tropical karst sites, for example Mulu, Phong Nha and South China Karsts, have been inscribed in recent years. The extensive and relatively unmodified karsts of Papua New Guinea could form a predominantly natural nomination, using three criteria of the World Heritage Convention:

(viii) be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in

the development of landforms, or significant geomorphic or physiographic features;

(ix) be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;

(x) contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Two tentative sites have been registered with IUCN:

The *Sublime Karsts of Papua New Guinea* comprise three main areas, two on the PNG mainland and one on New Britain. To the east of the formerly glaciated Star Mountains lie the overthrust limestone ridges of the Bahrman Range, bounded to the south by the massive Hindenburg Wall. The karst terrain here is underlain by large caves including Selminum Tem, which is 25km long (Gillieson, 1985). The Darai limestones are extremely variable in lithology and interbedded with shales and siltstones. Large springs emerge at the contact of the limestone and underlying shales. Neotectonics and mudflows associated with the glaciation have altered the karst drainage. Much of the area is uninhabited and it is in a pristine state.



Figure 8: The massive escarpment of the Hindenburg Wall is 600m high and is subject to frequent landslides. A spring emerges at the contact between limestone and underlying shales.

The second part of the Sublime Karsts is the Muller Range in the Southern Highlands, a remote karst area punctuated by deep dolines or tiankeng (James, 2005). Most of the area is uninhabited and is undergoing little change other than natural disturbances. This may change with oil and gas exploration active in the area. To the east is the large polje of the Lavani Valley, with sinking streams on the drainage divide between the Sepik and Fly Rivers. Finally the third part of the tentative nomination is the Nakanai karst of New Britain. There the limestone ranges are punctuated by deep tiankeng intersecting very large underground rivers (Audra *et al.*, 2011). The Muruk cave system is the deepest in the Southern Hemisphere at 1158m. The ranges and plateau have only a very sparse human population, with small villages on the lowlands. Until recently the rainforests have remained intact, but logging is now being carried out on the margins of the area.

The only World Heritage property that is genuinely comparable with the Sublime Karsts is the Lorentz National Park WHA, situated in West Papua at the other extremity of the Star Mountains. This contains extensive glaciated karst terrain and large sinking streams, as well as a wide range of vegetation types and associated wildlife on an altitudinal transect from nearly 5000m to sea level. There are current issues of illegal logging, wildlife poaching and road construction which are of concern to the World Heritage Committee. The Gunung Mulu WHA (Malaysia) is broadly comparable to the Sublime Karsts in terms of its high relief karst morphology and the intactness of its vegetation. It contains some of the longest and largest caves in Southeast Asia, while its rich biodiversity and ongoing ecological processes meet World Heritage criteria. The majority of the karst area is under lowland rainforest and is uninhabited, and there have been very significant efforts by the Malaysian government to ensure that management meets the Operational Guidelines of the World Heritage Convention.

The *Kikori River Basin / Great Papuan Plateau* extends over two million hectares and includes the extinct volcano of Mt Bosavi, polygonal karst on extensive Darai limestone and extensive river systems draining primary lowland rainforest. Nearly all the forest types found in PNG are present, from montane forests in

the north, intact lowland forests in the south, and the largest block of mangrove forest in the Pacific. The Ramsar listed Lake Kutubu is a basalt dammed water body formed in karst rocks; its outlet, the Mubi River, passes through at least two caves. The basin's natural systems remain in remarkably good condition with limited areas of human habitation. A World Heritage listing would provide a better focus for efforts to conserve biologically important areas and promote sustainable economic opportunities such as ecotourism and forest product harvest. The Kikori Basin is also the site of PNG's first major liquid natural gas development. A 220km long pipeline has been constructed and gas is now being delivered to a port near Kikori. Associated road developments will place extreme pressure on the environments of the Basin and allow access by loggers. A partnership between the pipeline consortium and WWF has led to the declaration of over 86,000 ha of protected areas so far. It has to be remembered that there is very little public land in New Guinea and that virtually all areas from the highest peaks down to the coast is owned either by an individual or by a clan. In Papua New Guinea a Wildlife Management Area (WMA) is the simplest form of protected area, protecting an area of land or water while retaining full power by landowners to manage their land. WMAs are managed by an elected committee formed by customary landowners. In the Kikori these include the Lake Kutubu Wildlife Management Area (24057 ha), Neiru WMA (3984 ha), Libano WMA (8250 ha) and Sulamesi WMA (49800 ha). Further interest has been shown by communities to establish other protected areas within the Kikori Basin.

Comparable areas to the Kikori Basin include the Manas Wildlife Sanctuary of India and the Sundarbans National Park of Bangladesh. Both these lowland forested areas have large river systems but have been placed on the World Heritage In Danger list. The Central Amazon Conservation Complex WHA makes up the largest protected area in the Amazon Basin (over 6 million hectares) and is one of the planet's richest regions in terms of biodiversity. Smaller areas include the Khao Yai National Park WHA of Thailand, which has large areas of riparian rainforest and associated karst mountains.



Figure 9: Beaver Falls on the lowland Mubi River is fed by karst springs emerging at the contact between Darai Limestone and the underlying Ieru Formation shales

It is necessary for a host country to be not only able to demonstrate that a site meets one or more of the criteria but that appropriate management is in place to conserve World Heritage values. Unfortunately, given the remoteness of the karst areas in PNG, it is difficult to envisage that the Department of Environment and Conservation in Port Moresby has the capacity to manage these areas on the ground without very extensive community conservation schemes. The development of a World Heritage

nomination for either the Sublime Karsts or the Kikori Basin-Great Papuan Plateau areas could only proceed following extensive negotiations with and consent of the traditional owners of the land, combined with significant assistance to PNG government staff from relevant overseas expertise in karst geomorphology, karst processes and in biology and ecology. The financial implications of this are very significant and will undoubtedly require overseas aid to be realised.

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