Mapping of Coastal Erosion/Degradation Hotspots in Kenya, Tanzania, Mozambique and Madagascar.

Antony Ndubi, Robinson Mugo, Lawrence Okello, Edward Ouko

Regional Centre for Mapping of Resources for Development

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Abstract.
Coastal and marine environmental degradation has continued to intensify in the coastal zones of Kenya, Tanzania, Mozambique and Madagascar. SERVIR Eastern and Southern Africa identified and mapped some of the erosion/degradation hotspots in these four coastal zones. A total of 40 hotspots were identified and mapped, 10 from each of the four coastal zones. Four different types of degradation hotspots were identified. The identified hotspots include: deforested areas, areas with sedimentation, areas with desolate open pits, and areas whose fresh water tables have been salinized. Among the degradation hotspots identified within the Kenyan coastal zone 4 of them were areas with salinized fresh water tables, 3 were deforested areas, 2 were areas with sediments, while the remaining 1 was an area with open desolate pits. In the Tanzanian coastal zone 4 hotspots were areas with sediments, 3 were deforested areas, and 3 were areas with salinized fresh water tables. Mozambique coastal zone had 4 deforested areas, 3 areas with sediments, and 3 areas with salinized fresh water tables. Madagascar coastal zone had 5 areas with sediments, 4 deforested areas, and 1 area with desolate open pits. The main drivers of coastal erosion/degradation in the four coastal zones were also identified. The drivers identified for deforestation are extraction of timber and poles for construction, cutting of trees for wood fuel and charcoal production, clearing of vegetation for cultivation and construction of settlements, and burning to create room for grazing. Sedimentation has clearing of vegetation for cultivation, constructing along the rivers, mining of minerals, and storms and tsunamis as the main drivers. For salinization of fresh water tables construction of salt pans is the main driver, while for desolate open pits it is mining of minerals. High resolution images from Digital Globe were used to prepare the coastal erosion/degradation hotspot maps. The Digital Globe images used are GeoEye-1 and WorldView2, both of 5 meter spatial resolution. In cases where GeoEye-1 and WorldView2 cloud free images were not readily available screenshot images from Google Earth were used.

Key words: *Coastal Zone, Hotspot, Erosion, Degradation, High Resolution.*

Introduction.

Over the past 30 years, some gains have been made in protecting the coastal and marine environments in developing countries, mainly in capacity building, awareness creation, research, and formulation of policy and institutional frameworks. However, coastal and marine environmental degradation not only continues but has also intensified as a result of an array of threats.

The major threats in coastal Eastern Africa include (but are not limited to) climate change (e.g., erratic and torrential rains leading to flooding and massive erosion/deposition), marine pollution (dumping of domestic and industrial waste), over exploitation of living marine resources, and coastal habitat loss. This is despite national and international efforts to address these problems. Coastal erosion/degradation is one of the biggest threats to marine biodiversity and ecosystems along the Eastern Africa coast.

Coastal erosion is causing loss of beaches and structures adjacent to beach fronts, loss of mangrove forests (which act as the first line of defence against rising sea levels and wave action), and smothering of submerged plants such as sea grasses. Pollutants and sediments discharged through river systems and resulting from floods highly affect the chemistry of lagoons' sea water, consequently threatening biological equilibrium.

One of the greatest impediments to coastal and marine conservation is the lack of reliable resource records and catalogues necessary to plan measures for protection, monitoring, mitigation, or restoration of coastal ecosystems.

Earth Observation information is useful in helping to find solutions for some of these challenges (http://servircatalogue.net/Product?product_id=76).

According to the Integrated Coastal Zone Management (ICZM) Protocol of the United Nations Convention on the Law of the Sea (UNCLOS), there is no single description of coastal zone. Boundaries are delineated on the basis of the particular problems that ICZM attempts to solve. The erosion/degradation hotspots that were mapped in this particular project are those that fall within 10 km buffer from the coastline.

Coastal erosion/degradation hotspots are areas within the coastal zone and with higher erosion/degradation rate as compared to adjacent areas or to the expected/historic rates (Kraus and Galgano, 2001). According to FAO (2003) Working Paper No. 15 (Environment and Natural Resources), hotspot refers to adverse aspects of the interface between agricultural activities and environmental processes. The hotspot concept can be used to identify situations that if left unattended can prove harmful, both to the environment and to those dependent on it (UNEP, 2009).

The Study Area.

The area of study has a geographic coverage of Kenya, Tanzania, Mozambique and Madagascar (*Figure 1*). This region lies between 29.33^{0}E and 50.83^{0}E, and 26.87^{0}S and 05.42^{0}N. These four countries have a coastline of 9,258 km total length. Kenya has the shortest coastline of all countries of Western Indian Ocean (WIO), at only 536 km. Tanzania's coastline extends for 1,424 km, Mozambique's is 2,470 km and Madagascar's is 4,828 km (Samoilys, et al., 2013).

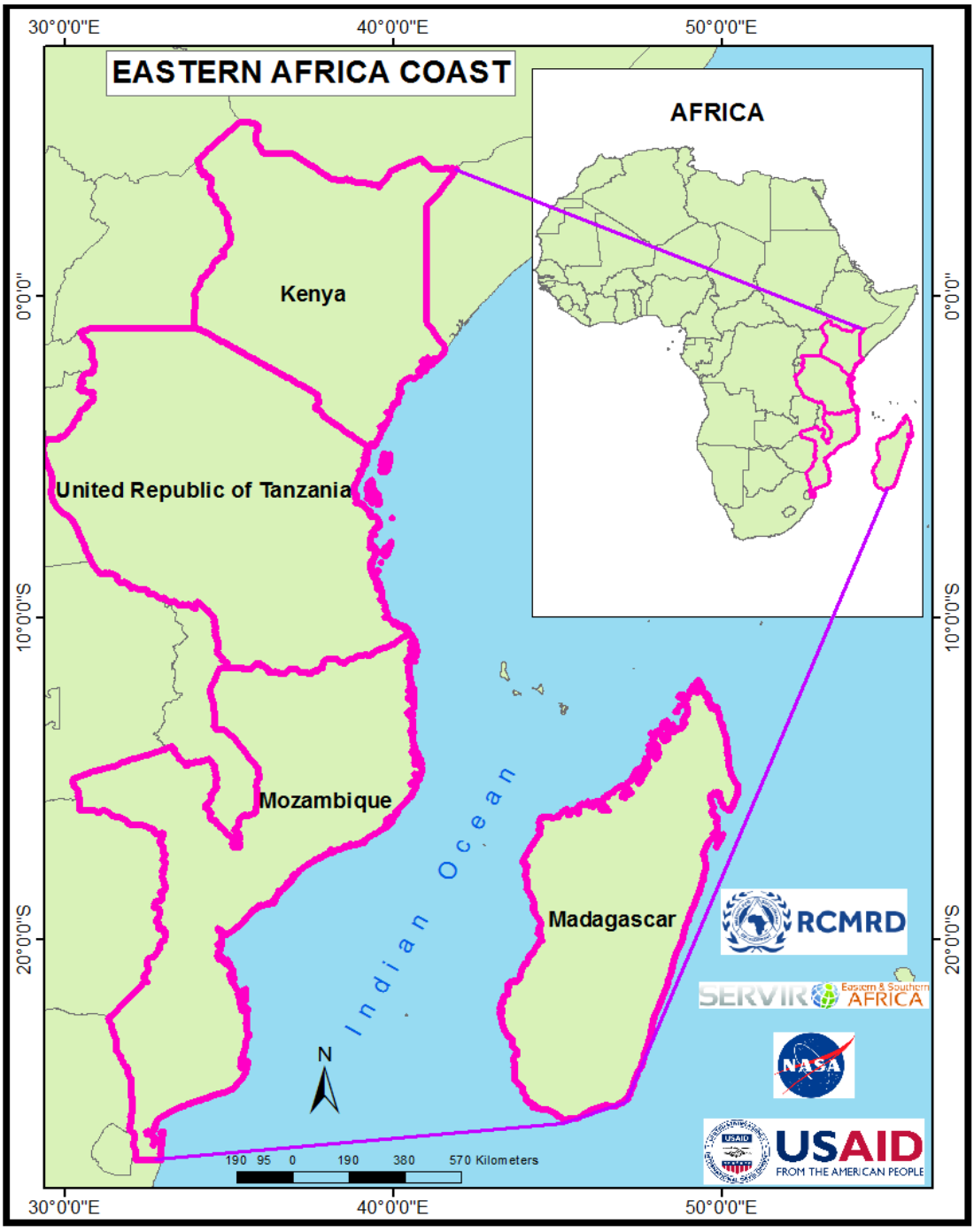


Figure 1: Geographic coverage of the area of study

Methodology.

Identification and mapping of coastal degradation hotspots was carried out through engagement of stakeholders, desktop information search, identification of locational coordinates, identification and acquisition of satellite images, and preparation of maps. *(Figure 2)*.

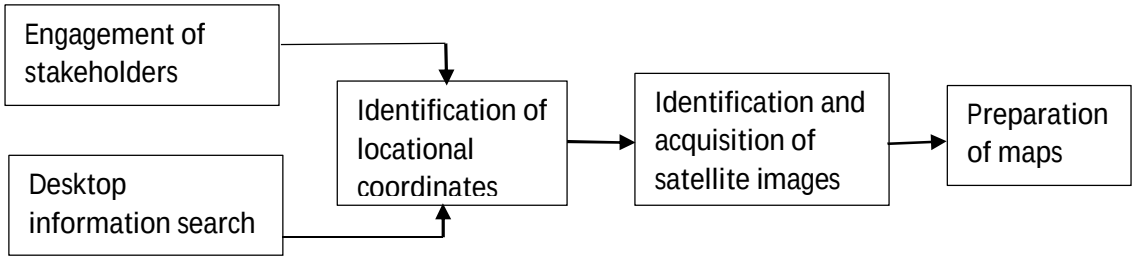


Figure 2: Coastal erosion/degradation hotspots mapping conceptual framework.

Engagement of stakeholders was done in workshops where participants were drawn from different partner organizations *(Figure 3)*. The engaged partner organizations include:

i. Kenya Marine and Fisheries Research Institute (KMFRI), Coastal Marine and Resource Development (COMRED), and Egerton University from Kenya.
ii. Tanzania Fisheries Research Institute (TAFIRI), University of Dar es Salaam, and Ardhi University from Tanzania.
iii. Centre for the Sustainable Development of Coastal Zones (CDS-ZC), and Universidade Eduardo Mondlane (UEM) from Mozambique.
iv. Institut Halieutique et des Sciences Marines (IHSM), and World Wide Fund for Nature (WWF) from Madagascar.

Workshop participants gave information on the location of degradation hotspots and their causative agents.

Figure 3: Stakeholder engagement workshop in Nairobi.

Desktop information search was done to gather more information on the location and causative agents of the degradation hotspots. The search involved reading online material and Google Earth searching on how the hotspots appear on satellite images *(Figure 4)*. Locational coordinates of the hotspots were also identified on Google Earth during the search and KML point layer digitized for conversion into a shapefile for map preparation and to be overlaid on satellite images for individual hotspot maps.

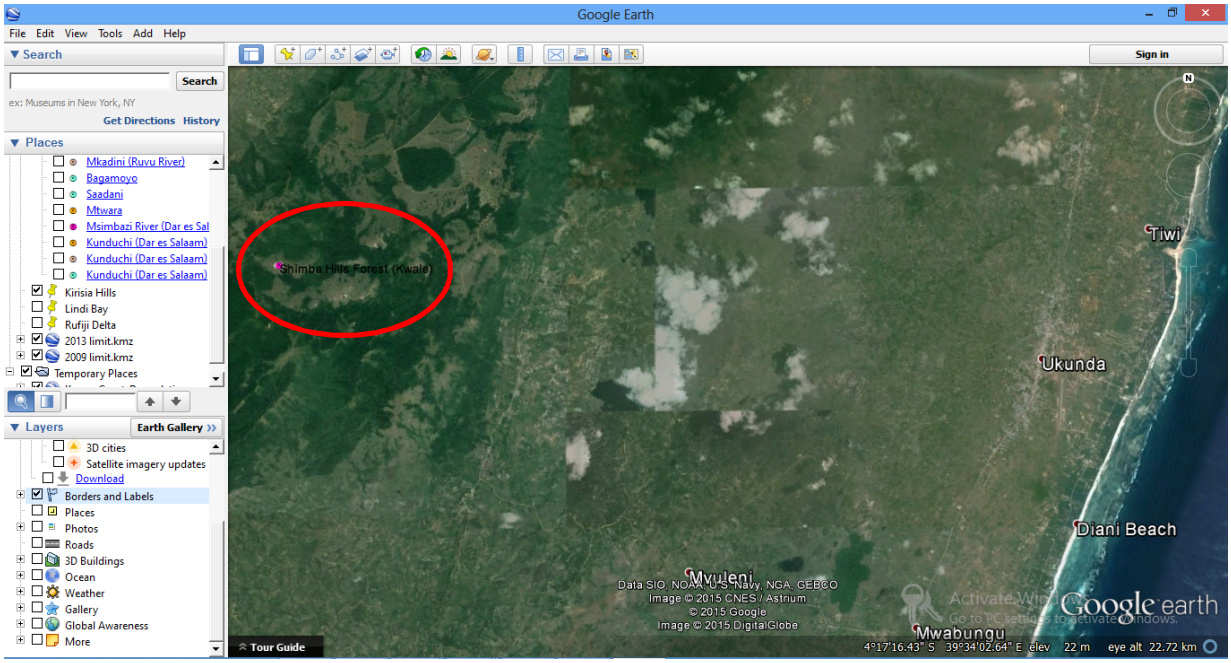


Figure 4: Degraded forest site as identified on Google Earth.

Cloud free high resolution satellite images covering the degraded hotspots were identified and sourced for. After acquiring the satellite images maps were prepared by overlaying hotspot point layer on the images. The high resolution images used were 0.5 meter GeoEye-1 and WorldView-2.

Results and Discussion.

A total of 40 coastal erosion/degradation hotspots were identified and mapped, 10 from each of the four coastal zones of Kenya *(Figure 5)*, Tanzania *(Figure 6)*, Mozambique *(Figure 7)* and Madagascar *(Figure 8)*. Four different types of degradation hotspots were identified. The identified hotspots include: deforested areas, areas with sedimentation, areas with desolate open pits, and areas whose fresh water tables have been salinized. Among the degradation hotspots identified within the Kenyan coastal zone 4 of them were areas with salinized fresh water tables, 3 were deforested areas, 2 were areas with sediments, while the remaining 1 was an area with open desolate pits *(Table 1)*.

The identified deforested areas in the Kenyan coastal zone are found in Shimba Hills Forest (Kwale), Arabuko Sokoke Forest (Kilifi) and Lamu mangroves. Arabuko Sokoke (370 km^2) and Shimba Hills (63 km^2) Forests are the two largest forests within the East African Coastal

Forest Mosaic (CEPF, 2005), while Lamu mangroves constitute the highest concentrations of the Kenyan mangroves (FAO, 2003).

Kipini and Takaungu areas that were identified with sedimentation are in the 27 km^2 Tana Estuary drained by Tana River (Kitheka, 2005) and Takaungu Creek in Kilifi respectively. Desolate open pits in Mombasa are caused by mining of shale which is available in large quantities at Nguu Tatu, west of Bamburi (NEMA, 2009). Areas with salinized fresh water tables were identified in Malindi areas of Marereni, Fundi Isa, Gongoni and Ngomeni. Salinization of fresh water tables occur in areas with constructed salt pans. Salt production takes place adjacent to the mangroves at Gongoni and Fundi Isa, north of Malindi. There are extensive salt pans at the Gongoni-Kurawa area (NEMA, 2009). Mangroves were cleared extensively in the Ngomeni swamps to pave way for the construction of salt pans (NEMA, 2009).

SITE NO.	DEGRADATION SITE	TYPE OF DEGRADATION	CAUSATIVE AGENT
1	Shimba Hills Forest (Kwale)	Deforestation	Timber extraction and charcoal production
2	Arabuko Sokoke Forest (Kilifi)	Deforestation	Timber extraction, wood carving and charcoal production
3	Lamu Mangroves (Lamu)	Deforestation	Building poles extraction and charcoal production
4	Kipini (Tana River)	Sedimentation	Clearing vegetation for cultivation
5	Takaungu (Kilifi)	Sedimentation	Clearing vegetation for cultivation
6	Nguu Tatu (Mombasa)	Desolate open pits	Open shale mining
7	Marereni (Malindi)	Salinized fresh water tables	Construction of salt pans
8	Fundi Isa (Malindi)	Salinized fresh water tables	Construction of salt pans
9	Gongoni (Malindi)	Salinized fresh water tables	Construction of salt pans
10	Ngomeni (Malindi)	Salinized fresh water tables	Construction of salt pans

Table 1: Coastal erosion/degradation hotspots in the Kenyan coastal zone.

In the Tanzanian coastal zone 4 hotspots were areas with sediments, 3 were deforested areas, and 3 were areas with salinized fresh water tables *(Table 2)*. The 3 deforested areas are found in Jozani Forest (Zanzibar), Pande Forest and Msimbazi River mangroves (Dar es Salaam). The major coastal forests in Tanzania have disappeared by more than 30% due to human activities, and this can make the Tanzanian coast more vulnerable to climate change and reduce the forests capacity to take up carbon (Chaisamba and Levira, 2013). Places identified to have salt pans that lead to salinization of fresh water tables are located in Bagamoyo,

Saadani and Kunduchi (Dar es Salaam). Sedimented areas were identified to be located at Mkadini on Ruvu River, Kunduchi (Dar es Salaam), Lindi Bay and Rufij Delta.

SITE NO.	DEGRADATION SITE	TYPE OF DEGRADATION	CAUSATIVE AGENT
1	Jozani Forest (Zanzibar)	Deforestation	Agricultural encroachment, charcoal production and firewood extraction
2	Pande Forest	Deforestation	Burning to create room for grazing
3	Msimbazi River (Dar es Salaam)	Deforestation (removal of mangroves)	Building poles extraction
4	Mkadini (Ruvu River)	Sedimentation	Clearing of vegetation for construction and cultivation
5	Kunduchi (Dar es Salaam)	Sedimentation	Urbanization (construction along the river)
6	Lindi Bay	Sedimentation	Storms and tsunamis
7	Rufiji Delta	Sedimentation	River upstream cultivation of land
8	Bagamoyo	Salinized fresh water tables	Construction of salt pans
9	Saadani	Salinized fresh water tables	Construction of salt pans
10	Kunduchi (Dar es Salaam)	Salinized fresh water tables	Construction of salt pans

Table 2: Coastal erosion/degradation hotspots in the Tanzanian coastal zone.

Mozambique coastal zone had 4 deforested areas, 3 areas with sediments, and 3 areas with salinized fresh water tables *(Table 3)*. Deforested areas were identified in mangrove areas of Rovuma Estuary, Quiterajo, Ibo and Joannise (Maputo Bay). Mozambique has the largest mangrove forest in Eastern Africa with about 400,000 ha of mangroves. The deforestation of mangrove as a source of fuelwood and timber, particularly in centres with high population, is now the main threat to mangroves in Mozambique (Republic of Mozambique, 2009). Areas with sediments were identified at Rovuma River, Quiterajo and Memba. Those that have salinized fresh water tables were identified at Libambai, Nazimoja and Matola. The problem of salinity is aggravated by inadequate water management and poor drainage systems (Famba, 2010).

SITE NO.	DEGRADATION SITE	TYPE OF DEGRADATION	CAUSATIVE AGENT
1	Rovuma Estuary	Deforestation	Construction of settlements
2	Quiterajo	Deforestation	Cultivation of crops
3	Ibo	Deforestation	Cultivation of crops
4	Joannise (Maputo Bay)	Deforestation	Wood fuel extraction
5	Rovuma River	Sedimentation	Cultivation of crops
6	Quiterajo	Sedimentation	Cultivation of crops
7	Memba	Sedimentation	Cultivation of crops
8	Libambai	Salinized fresh water tables	Construction of salt pans
9	Nazimoja	Salinized fresh water tables	Construction of salt pans
10	Matola	Salinized fresh water tables	Construction of salt pans

Table 3: Coastal erosion/degradation hotspots in the Mozambique coastal zone.

Madagascar coastal zone had 5 areas with sediments, 4 deforested areas, and 1 area with desolate open pits *(Table 4)*. Deforested areas were identified at Nosy Be Island, Ifotaka, Mahavelo and Kobakara. Most of the deforestation results from agricultural activities. In Madagascar, the production of rice, coffee, vanilla and spices accounts for about 80% of the national economy, and this exerts continual pressure on remaining forested areas (CEPF, 2000). Areas with sediments were identified at Onibe River, Betsiboka River and Estuary, Helodrano Mahajambe, River Manombo and Ampatsinakoho. Desolate open pits were identified at Andranodambo area. These pits are as a result of mining sapphire mineral which also causes sedimentation. Although sapphires and other gemstones have been known to exist in Madagascar since the 16th Century, widespread mining is a relatively recent phenomenon, with the real boom starting in the early 1990s (WWF, 2012).

SITE NO.	DEGRADATION SITE	TYPE OF DEGRADATION	CAUSATIVE AGENT
1	Nosy Be Island	Deforestation	Agricultural development
2	Ifotaka	Deforestation	Agricultural development
3	Mahavelo	Deforestation	Agricultural development
4	Kobakara	Deforestation	Agricultural development
5	Onibe River	Sedimentation	Agricultural development
6	Betsiboka River and Estuary	Sedimentation	Agricultural development
7	Helodrano Mahajambe	Sedimentation	Agricultural development
8	River Manombo	Sedimentation	Sapphire mineral mining
9	Ampatsinakoho	Sedimentation	Agricultural development
10	Andranodambo	Desolate open pits	Sapphire mineral mining

Table 4: Coastal erosion/degradation hotspots in the Madagascar coastal zone.

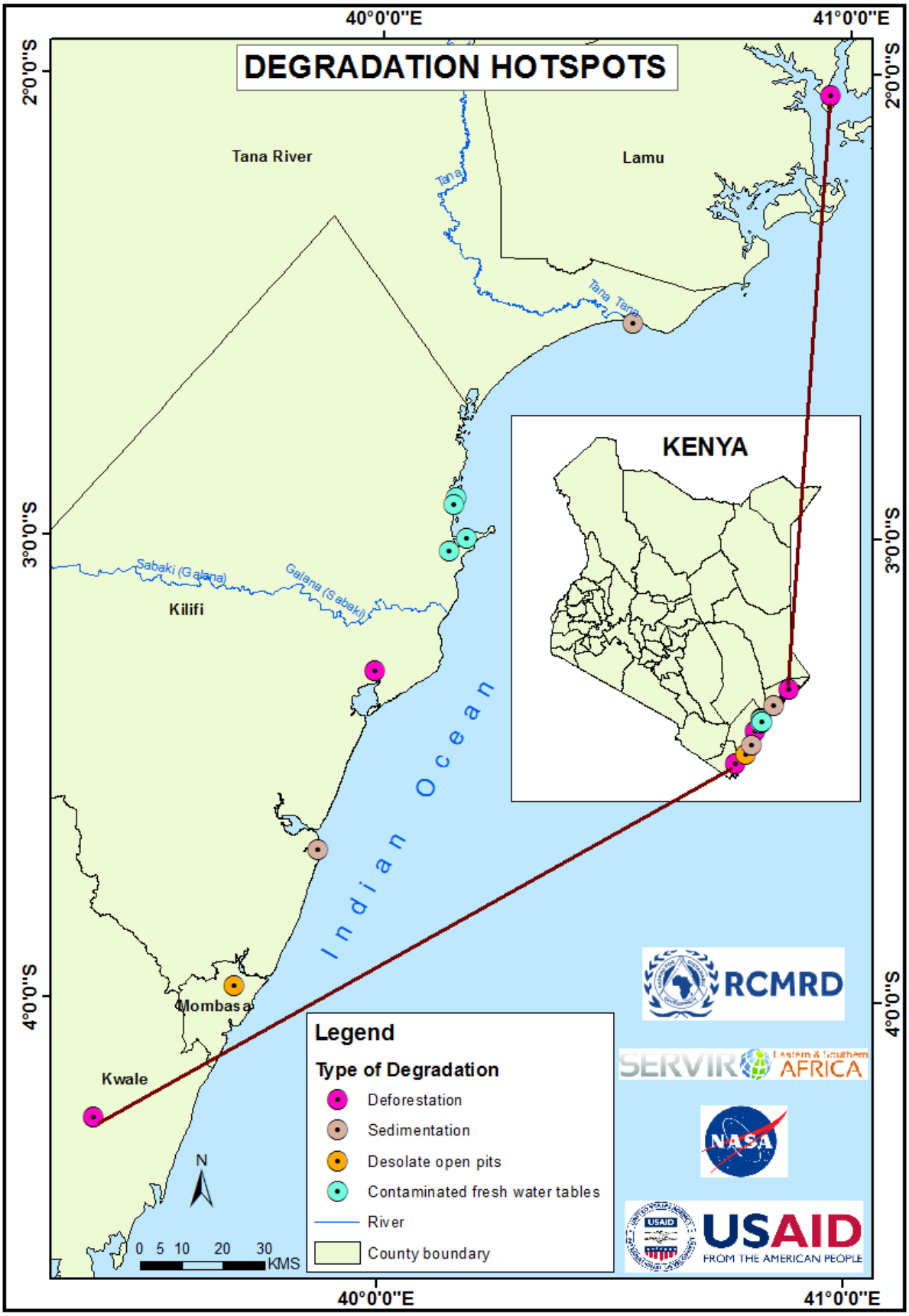


Figure 5: Coastal erosion/degradation hotspots in the Kenyan coastal zone.

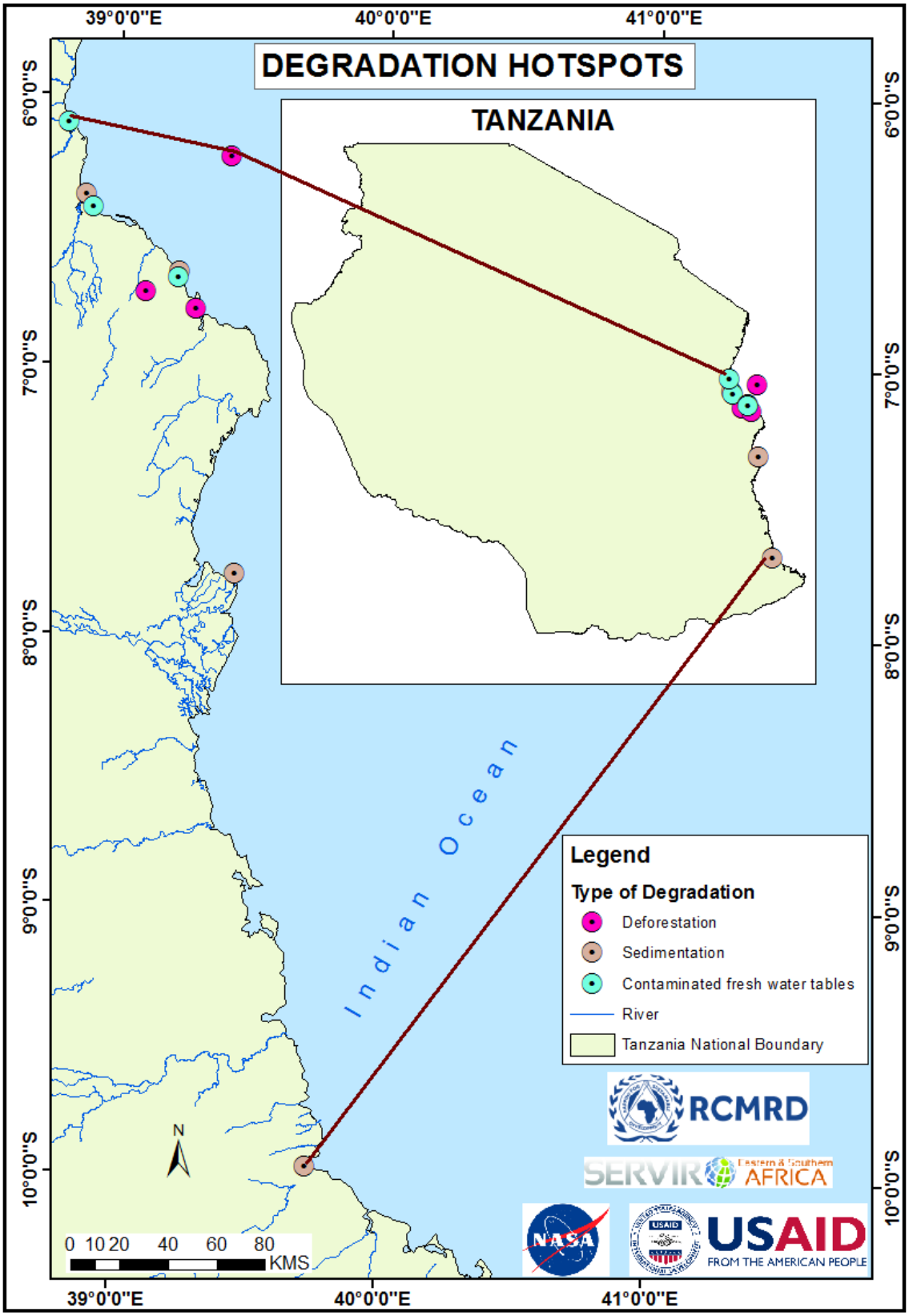


Figure 6: Coastal erosion/degradation hotspots in the Tanzanian coastal zone.

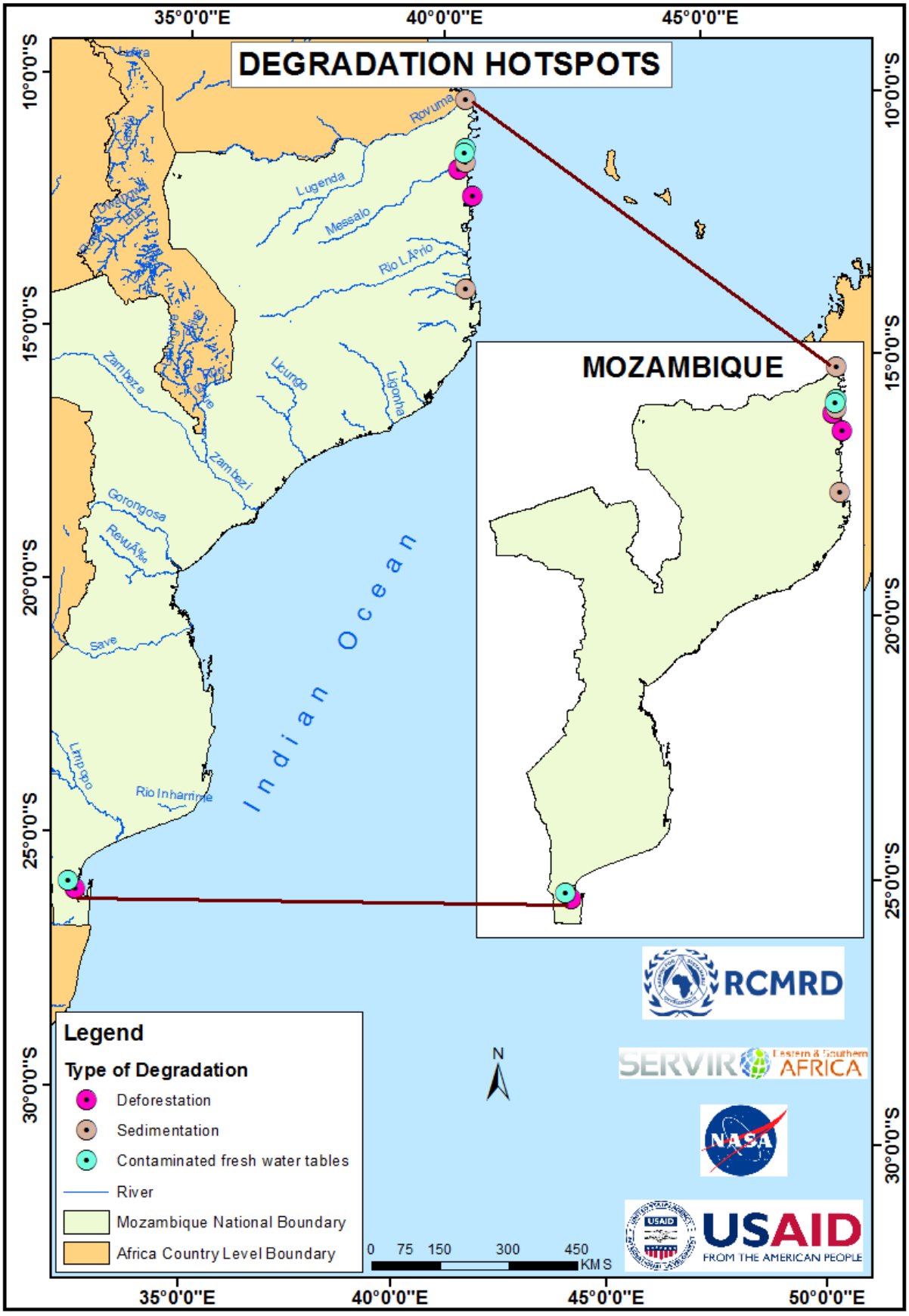


Figure 7: Coastal erosion/degradation hotspots in the Mozambique coastal zone.

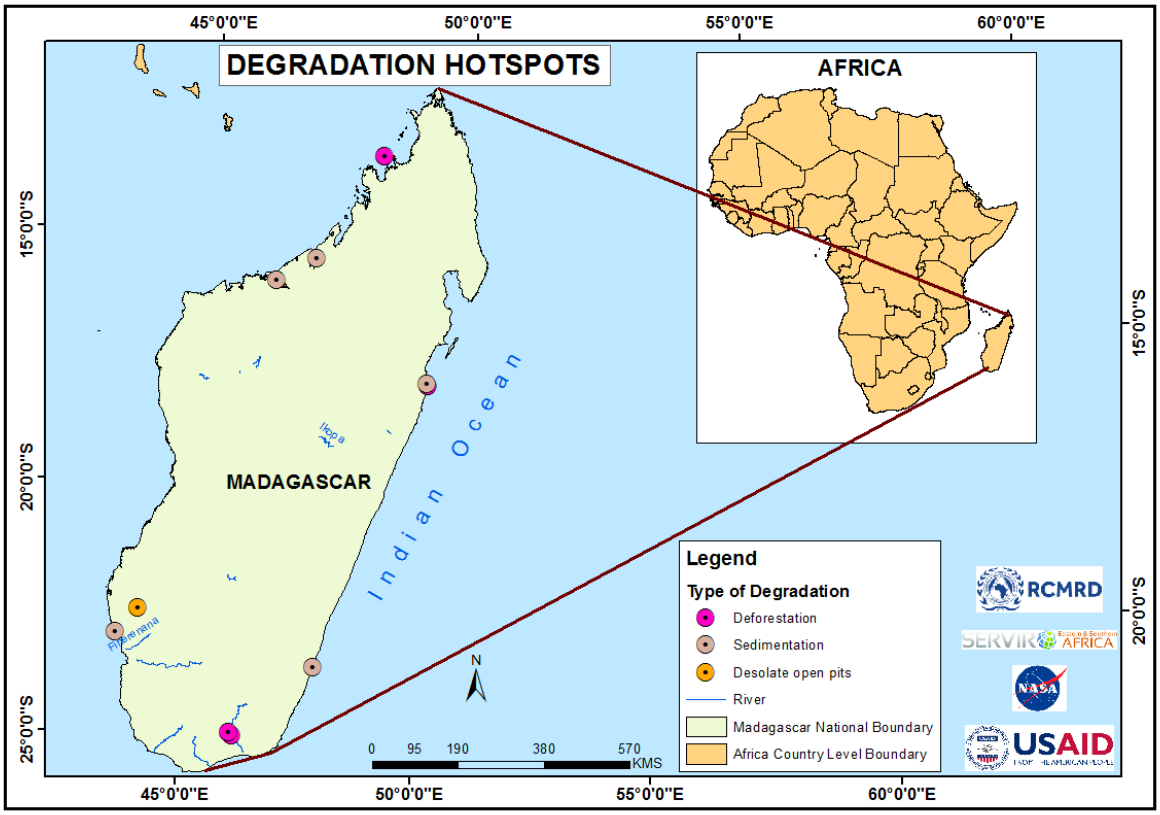


Figure 8: Coastal erosion/degradation hotspots in the Madagascar coastal zone.

Conclusion.

This study identified some of the erosion/degradation hotspots in the four coastal zones. The main drivers of the degradation at the hotspots were also identified. The drivers identified for deforestation are extraction of timber and poles for construction, cutting of trees for wood fuel and charcoal production, clearing of vegetation for cultivation and construction of settlements, and burning to create room for grazing. Sedimentation has clearing of vegetation for cultivation, constructing along the rivers, mining of minerals, and storms and tsunamis as the main drivers. For salinization of fresh water tables construction of salt pans is the main driver, while for desolate open pits it is mining of minerals.

Recommendation.

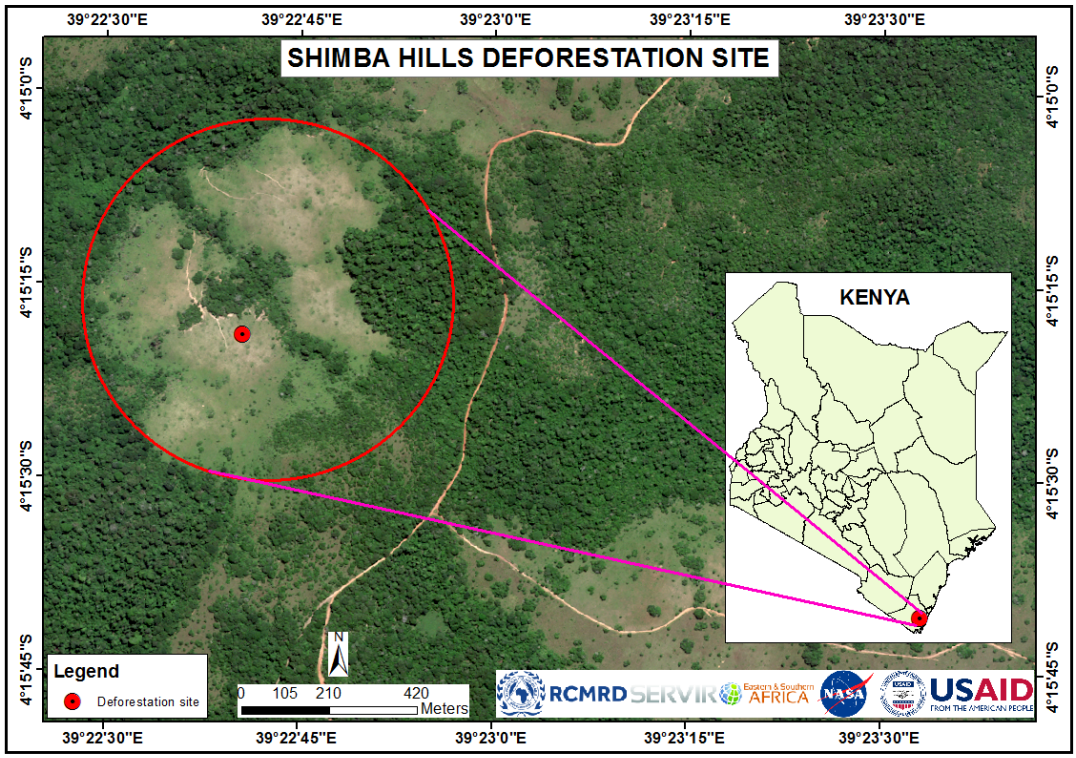
There is need for ground observations to enable identification of more erosion/degradation hotspots and gather more information on the already identified ones.

Appendices.

Appendix 1: List of stakeholder workshop participants.

COUNTRY	INSTITUTION	PARTICIPANT	EMAIL/TELEPHONE
KENYA	KMFRI	Victot Mwakha Alati	vmwakha@gmail.com (+254)726596621
	COMRED	Titus Jefwa Charo	tjefwa@yahoo.com (+254)737277421
	Kenya Marine & Fisheries Research Institute (KMFRI)	Ms. Stella Choge	stellahchoge@rocketmail.com (+254)713633081
	Egerton University	Dr. Benard Kirui	kiruib@yahoo.com (+254)722985542
TANZANIA	TAFIRI	Muhaji Abdillah Chande	muhajichande@yahoo.com +255 713 286 815
	UDSM - IMS	Pagu Julius Iswalala	juliuspagu@yahoo.com (+255)786604434
	University of Dar es Salaam – Institute of Marine Sciences (UDSM-IMS)	Dr. Mwita Marwa Mangora	mangora@ims.udsm.ac.tz; mmangora@yahoo.com (+255)783601848/(+255)713272896
	Ardhi University	Dr. Joseph Stephen Mayunga	mayungax@gmail.com (+255)768021824
MOZAMBIQUE	University Eduardo Mondlane (UEM)	Dórsia Marinela Timóteo langa	dorsia.marinela@gmai.com (+258) 825123065)
	University Eduardo Mondlane (UEM)	Henriques Jacinto Balidy	balidy.balidy@gmail.com (+258) 824476180
	University Eduardo Mondlane (UEM)	Mr. Hugo Mabilana	h.mabilana@gmail.com (+258)827002017
	Centre for the Sustainable Development of Coast Zones (CDS-ZC)	Mr. Micas Mechisso	mmechisso@gmail.com (+258) 824568220.
MADAGASCAR	WWF Western landscape	Oly Dannick Randriamanantena	drandriamanantena@wwf.mg (+261) 34 49 850 06
	WWF Western landscape	Anjaratiana Judicael Rakotondrazafy	jrakotondrazafy@wwf.mg (+261) 34 810 02
	WWF GIS Specialist	Anjara Jaon' Paritra Andriamanalina	AAndriamanalina@wwf.mg
	(IHSM)	Danny Kornélio Ravelojaona	korneliodanny@ihsm.mg (+261) 34 09 993 62

Appendix 2: Degradation hotspots maps in the Kenyan coastal zone.



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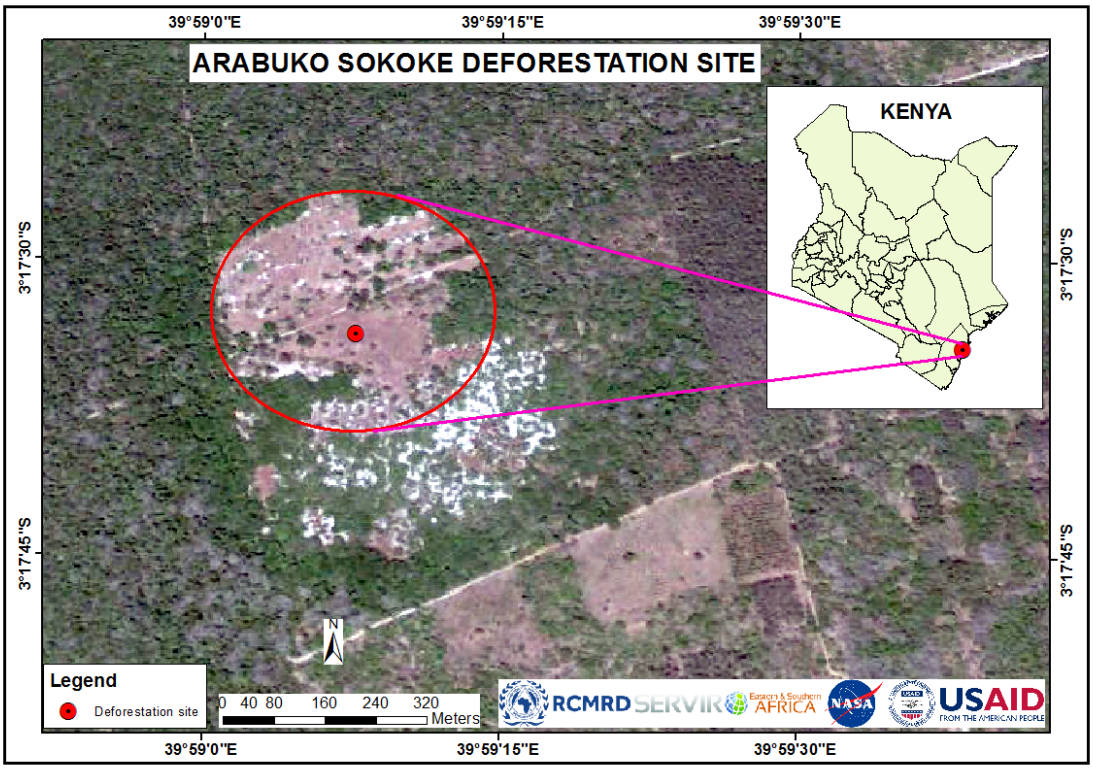

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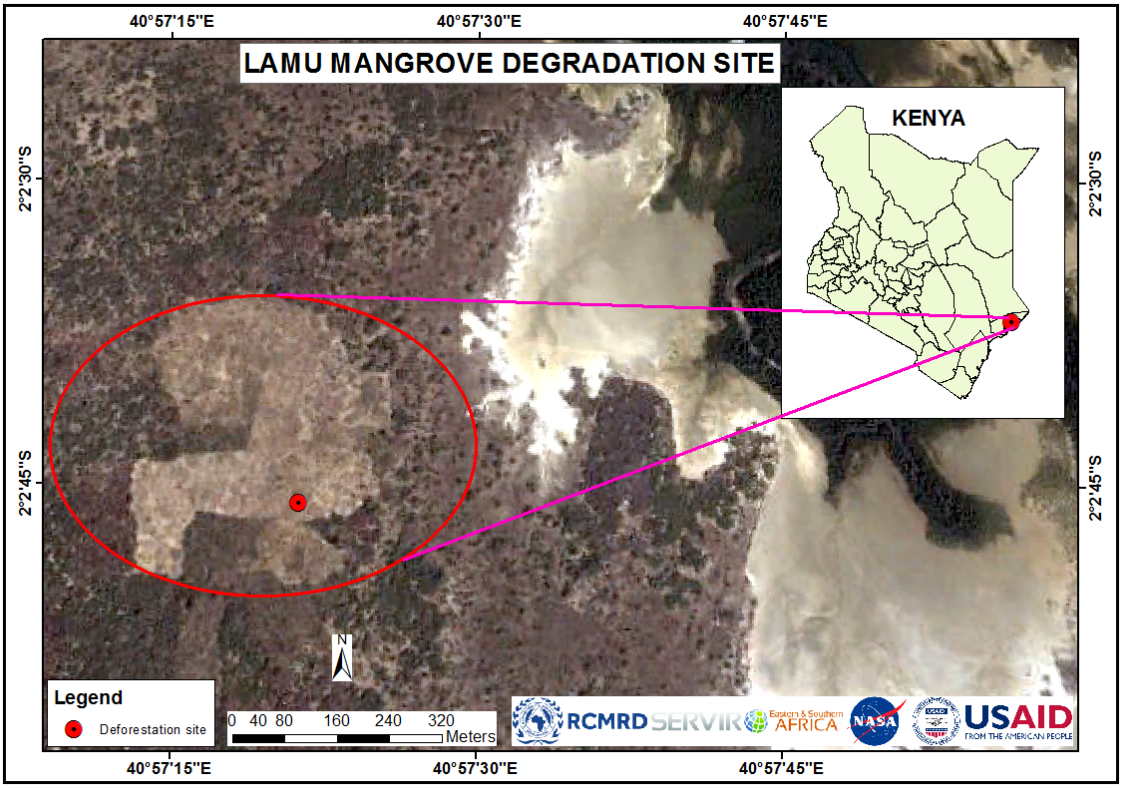

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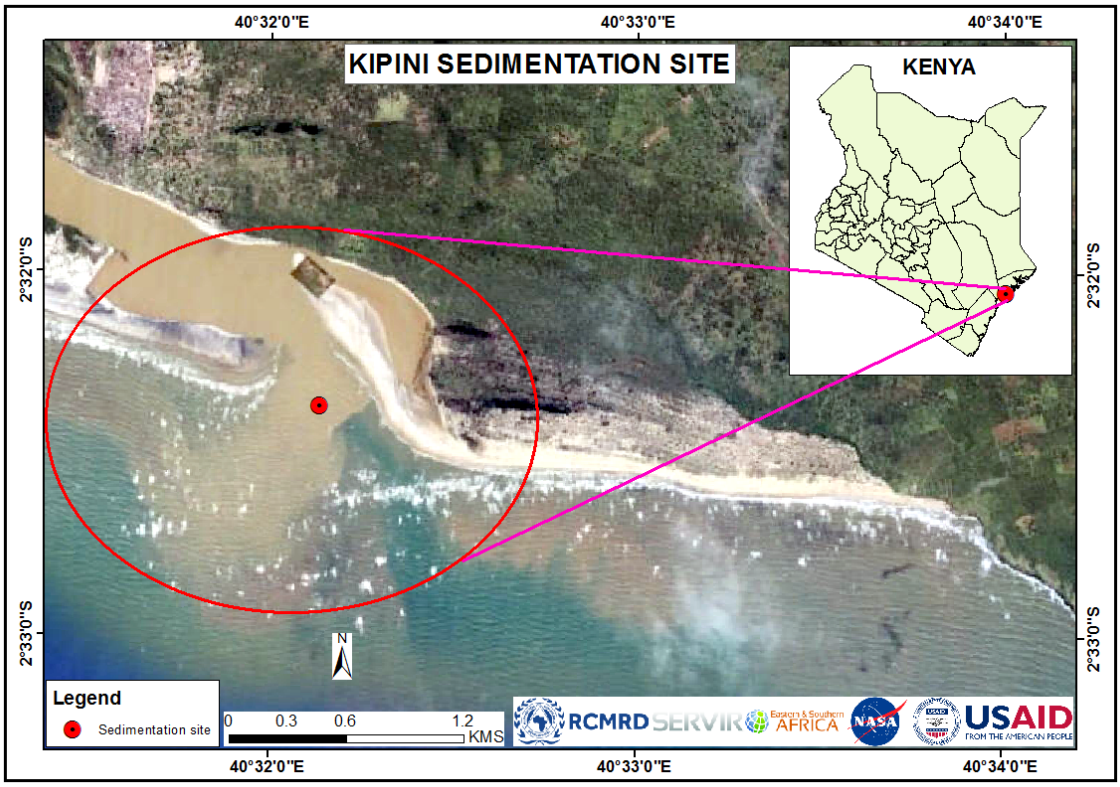

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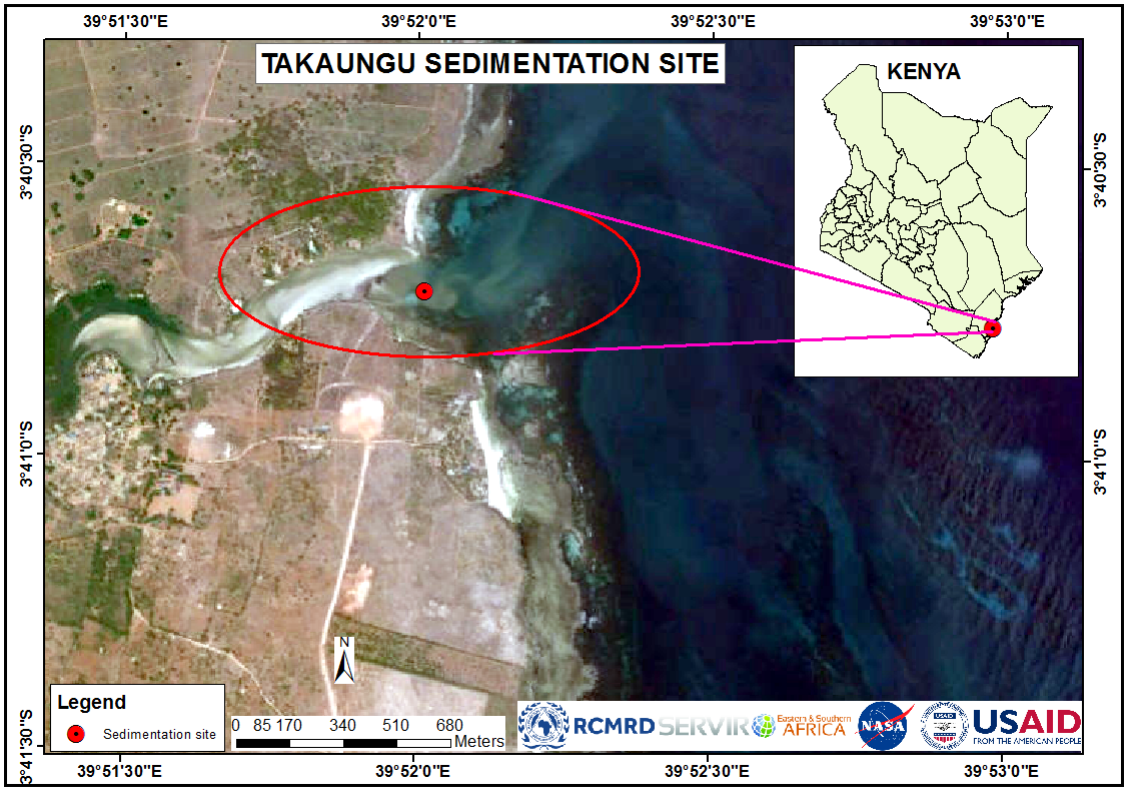

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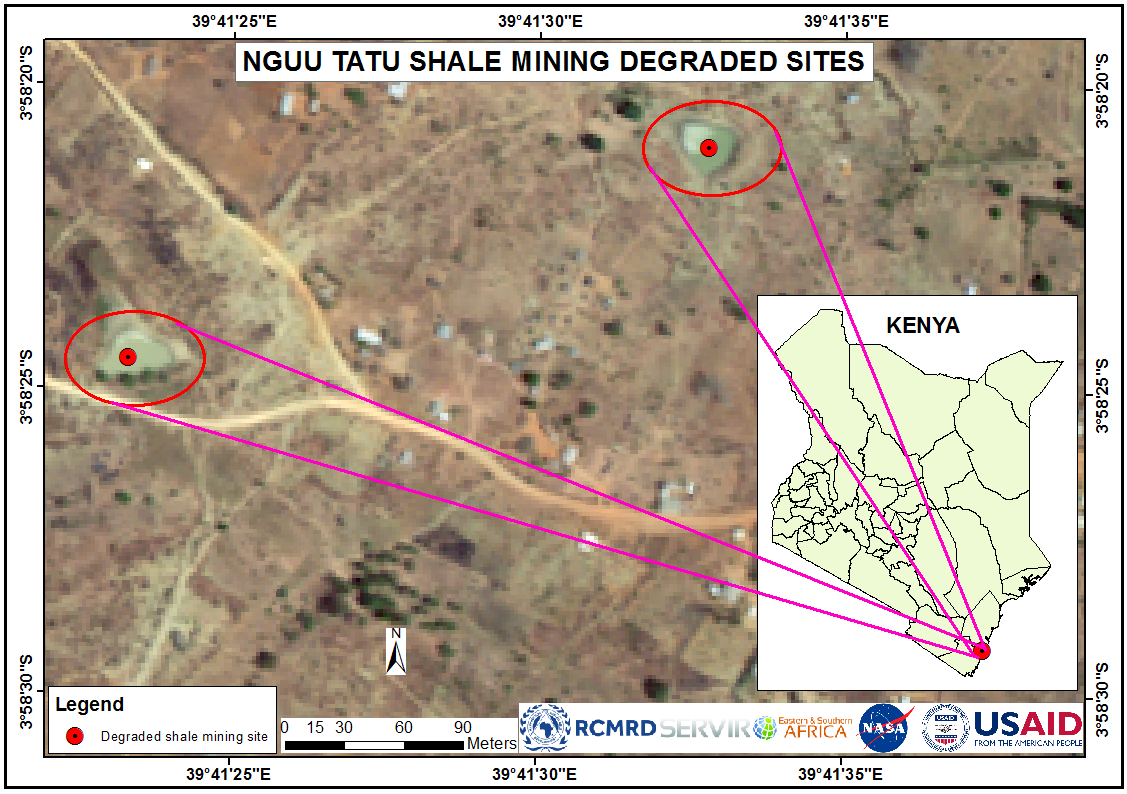

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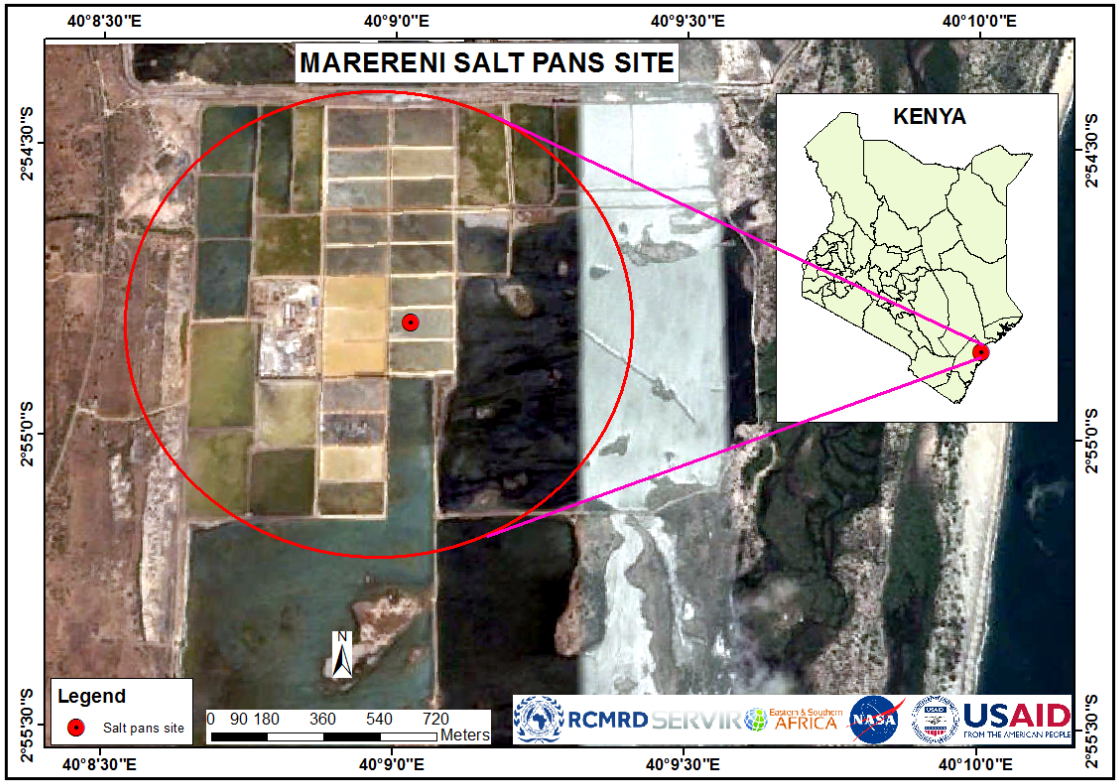

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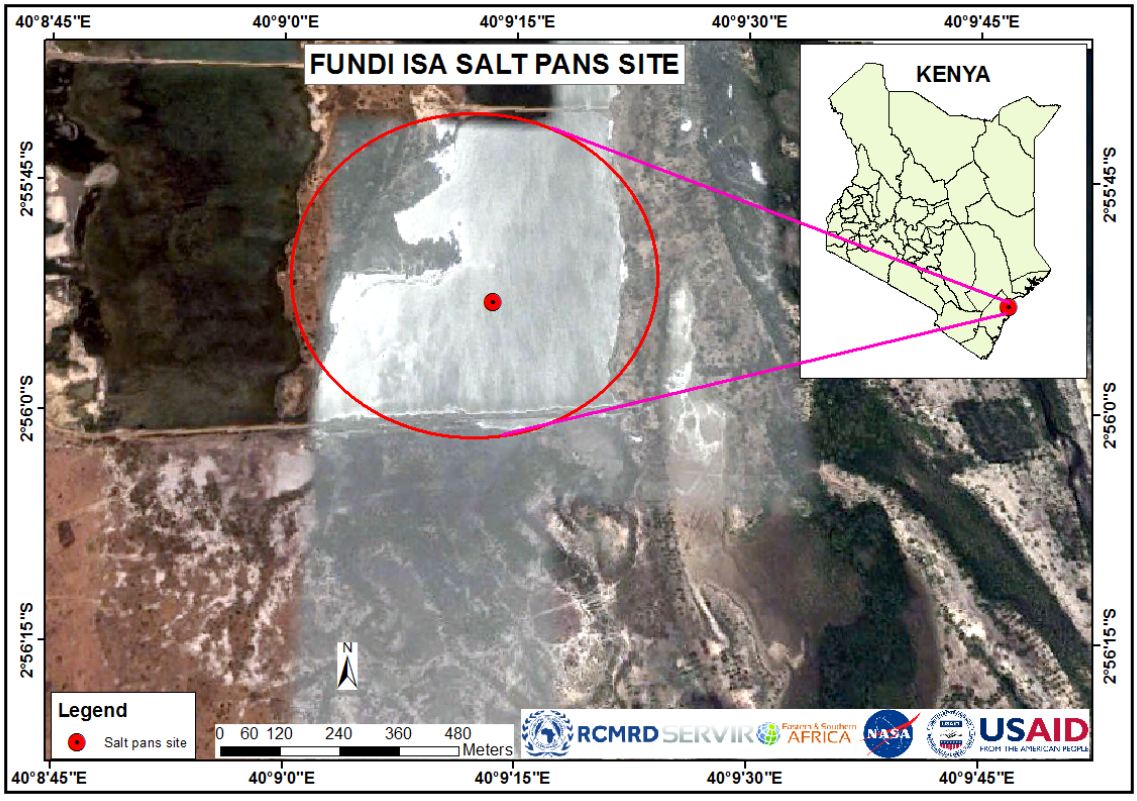

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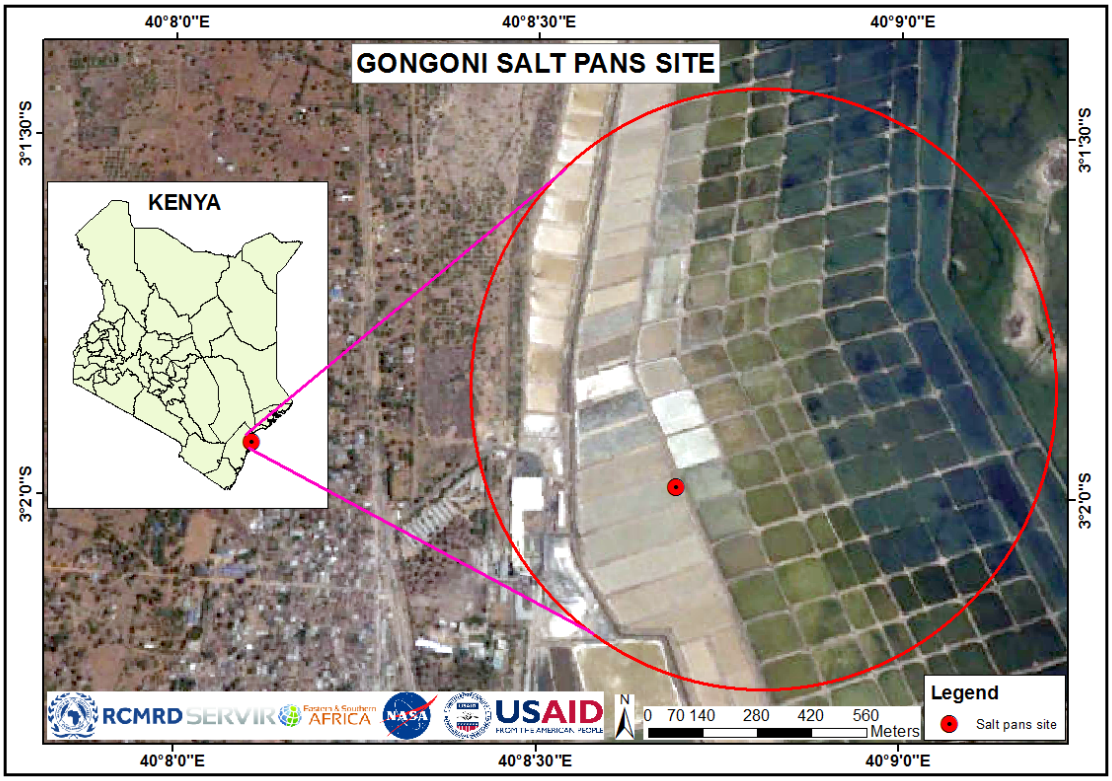

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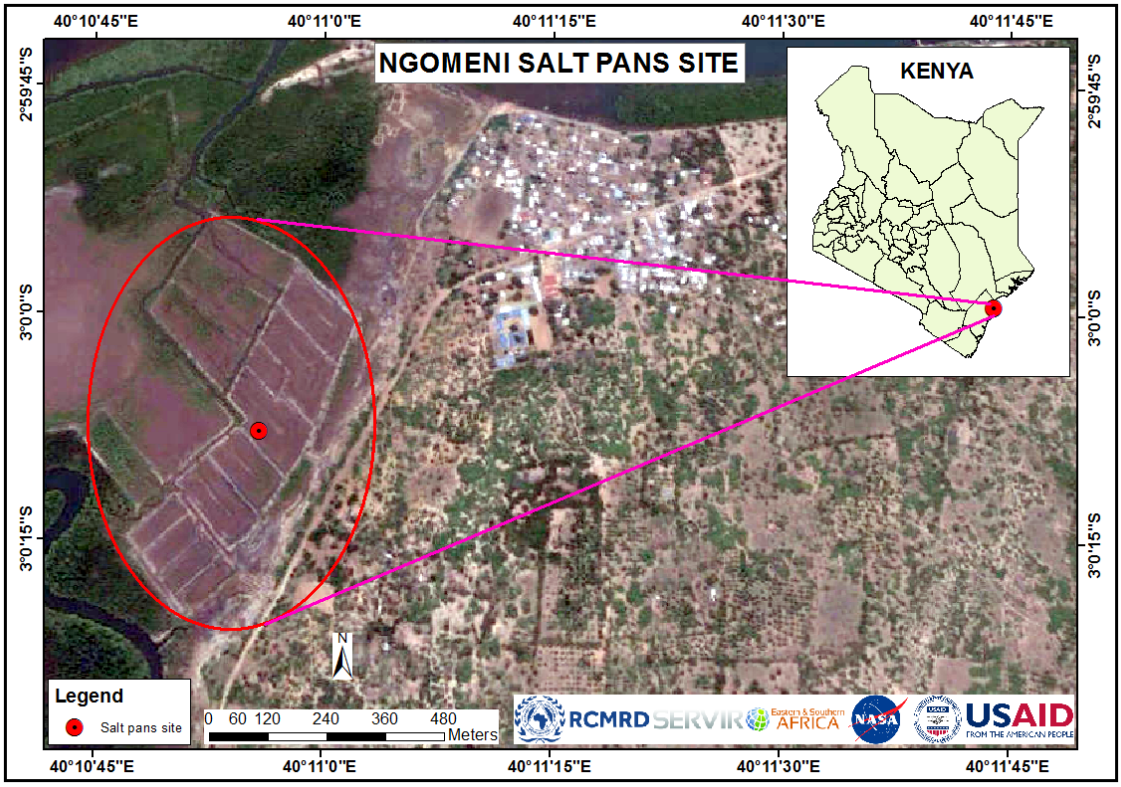

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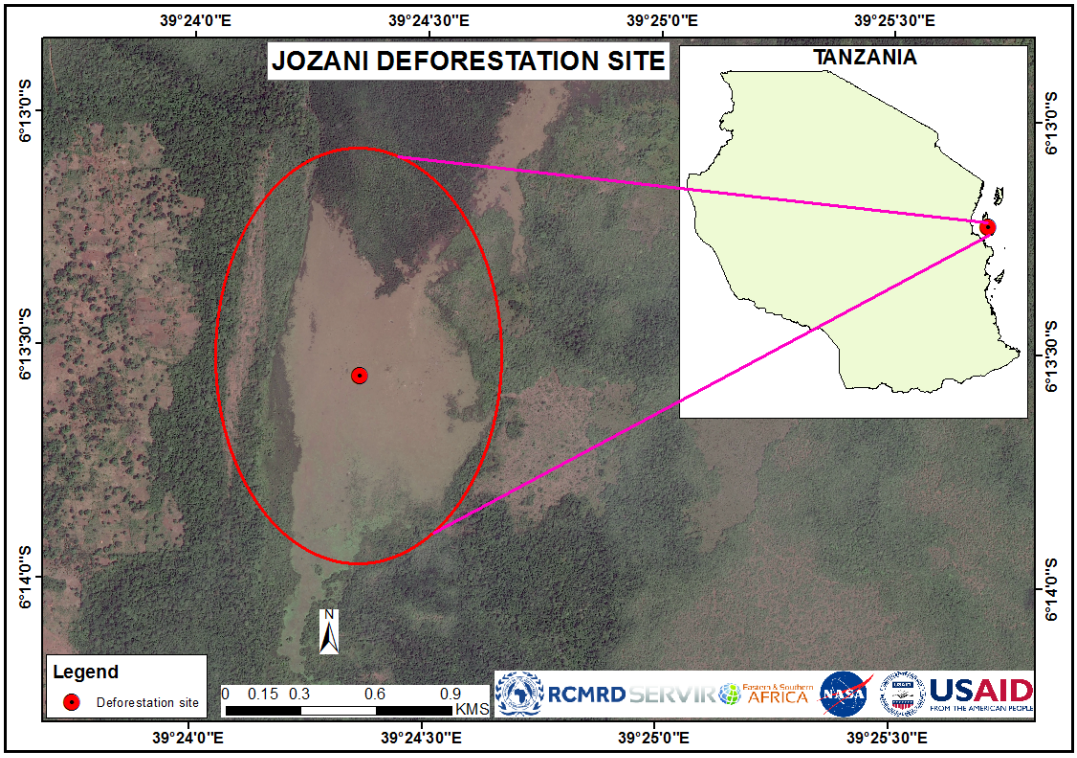
Appendix 3: Degradation hotspots maps in the Tanzanian coastal zone.



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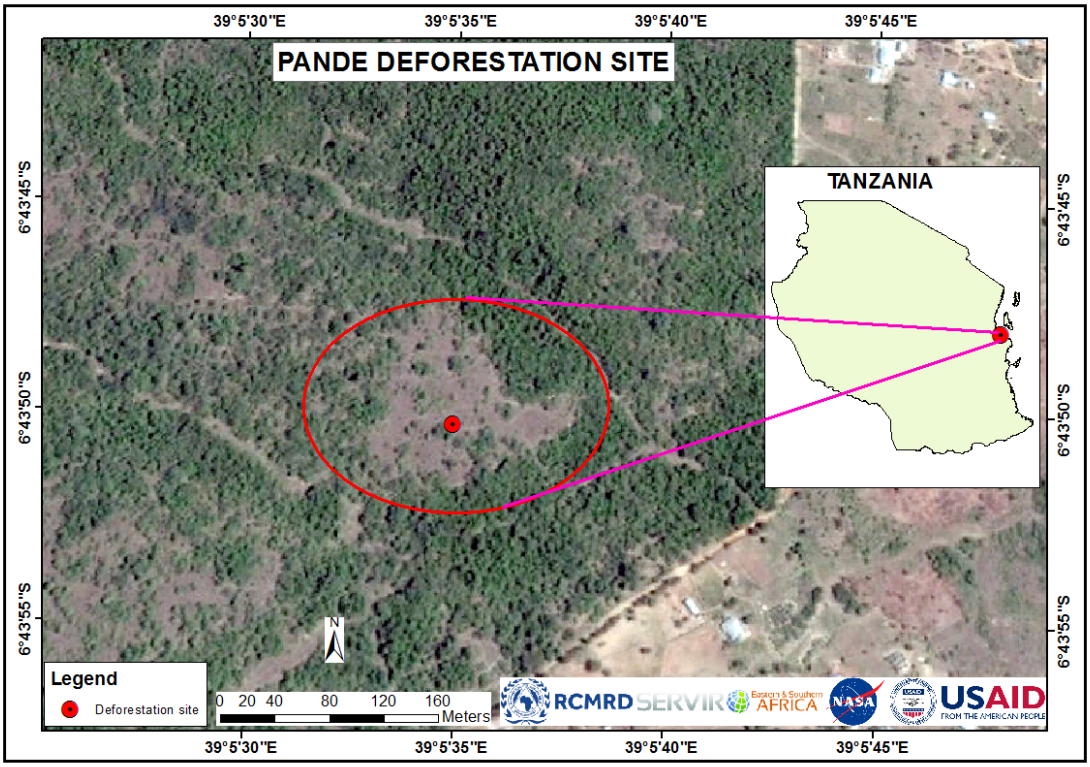

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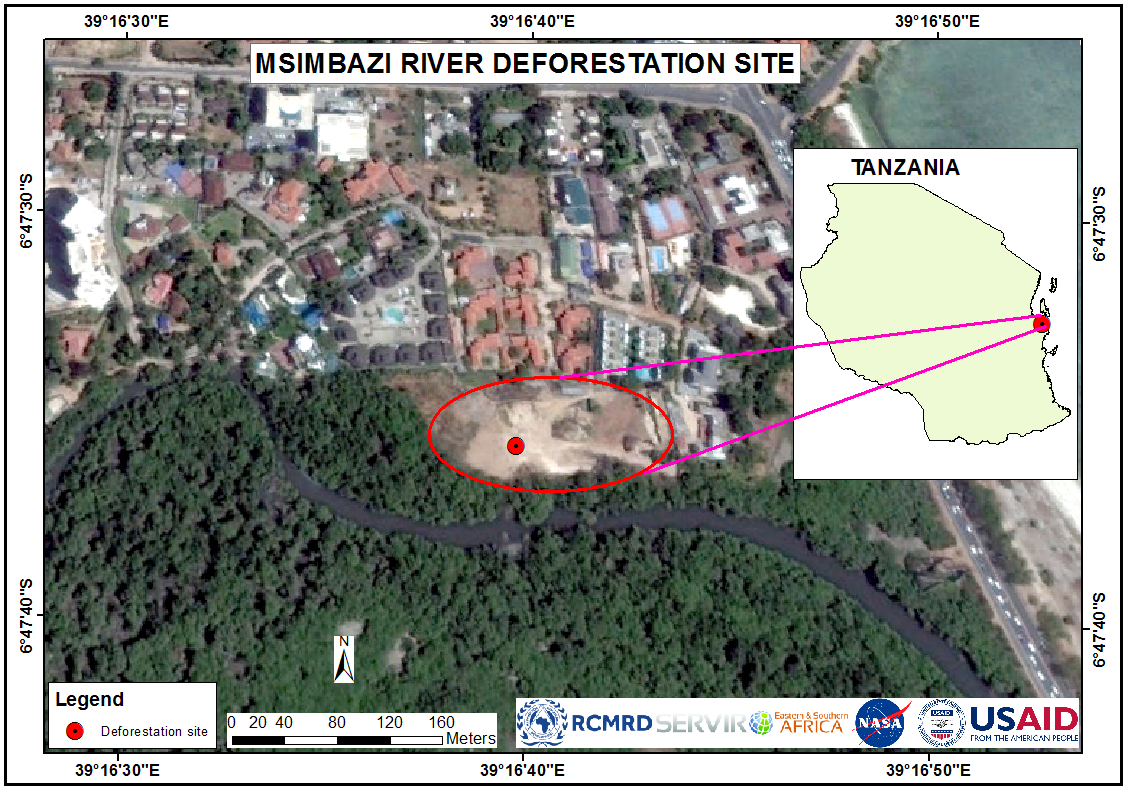

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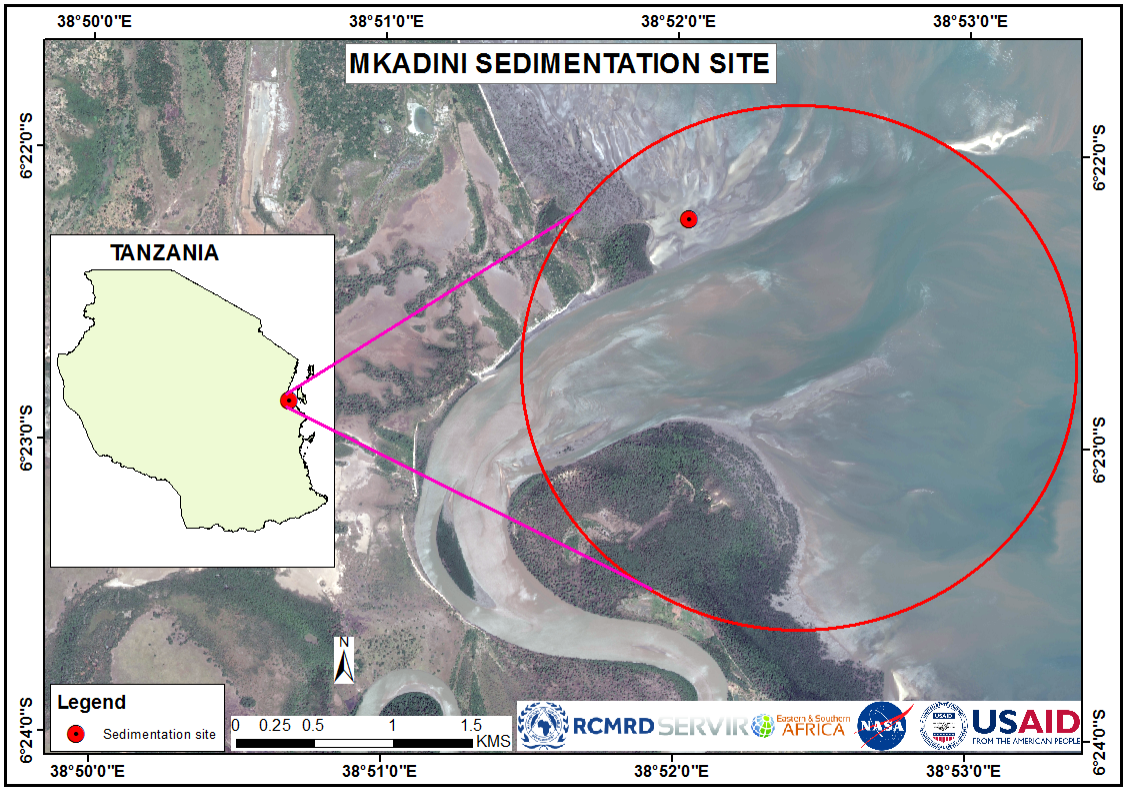

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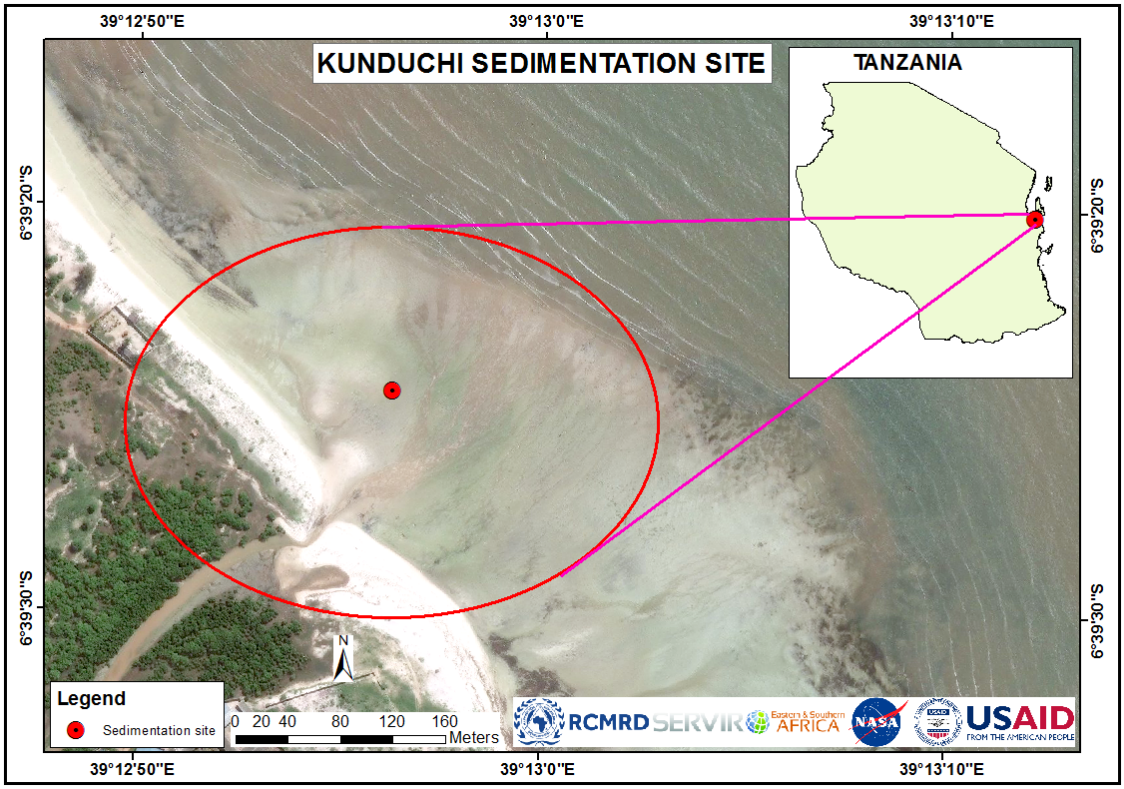

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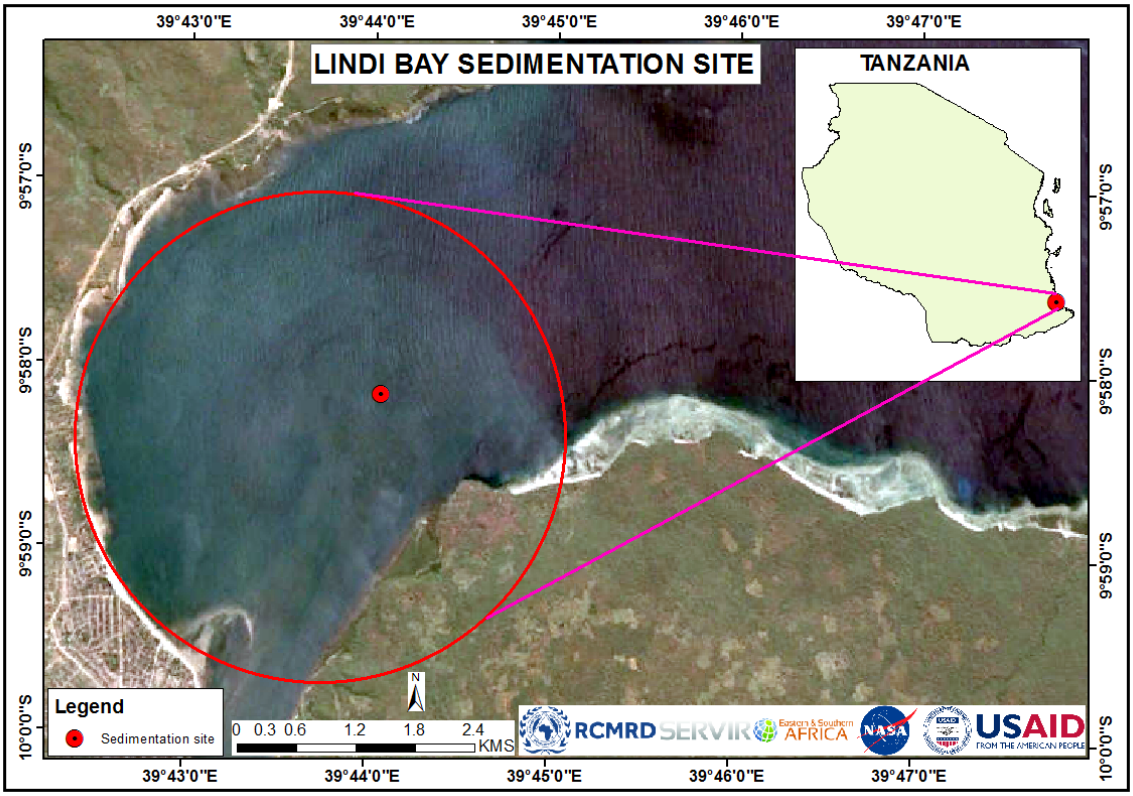

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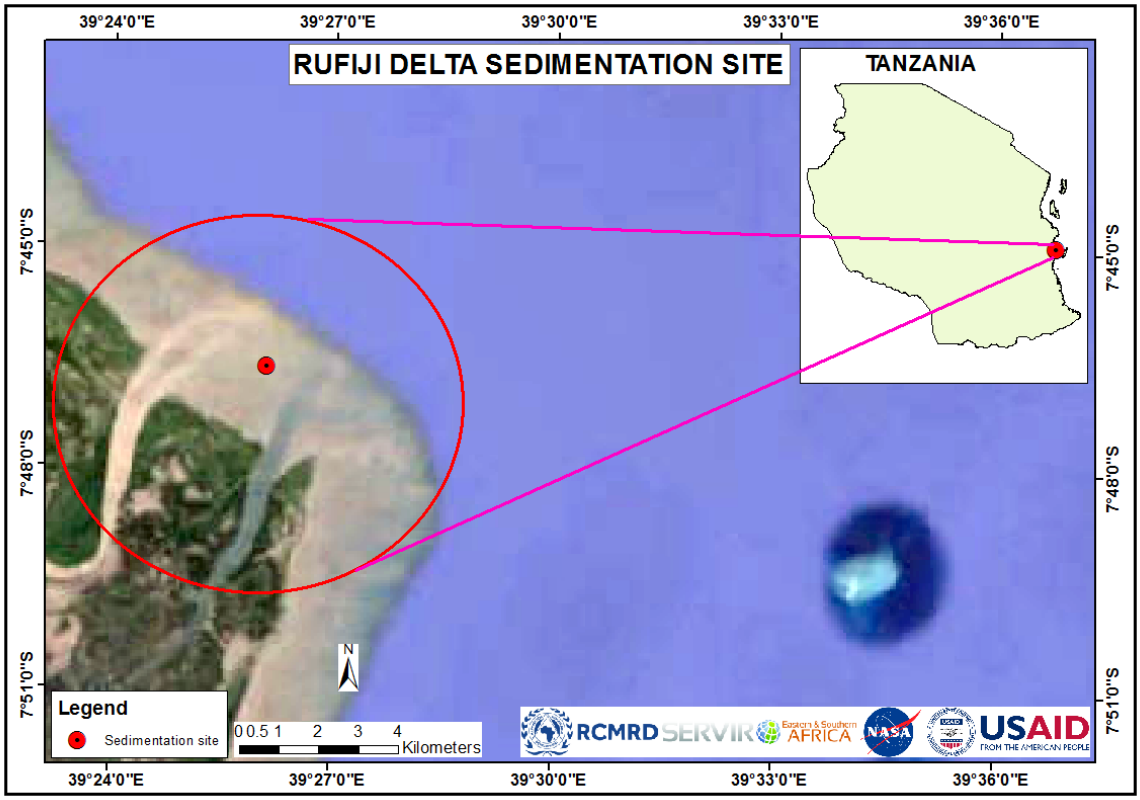
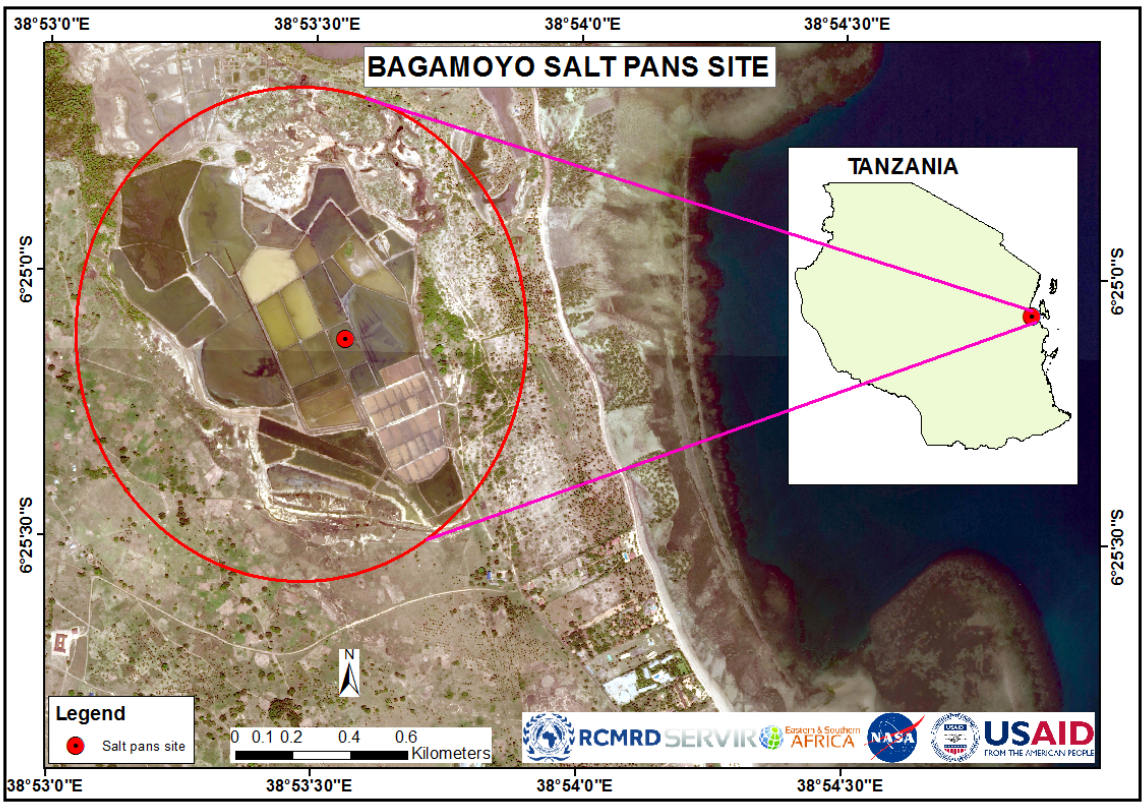


Image source: CNES/Astrium



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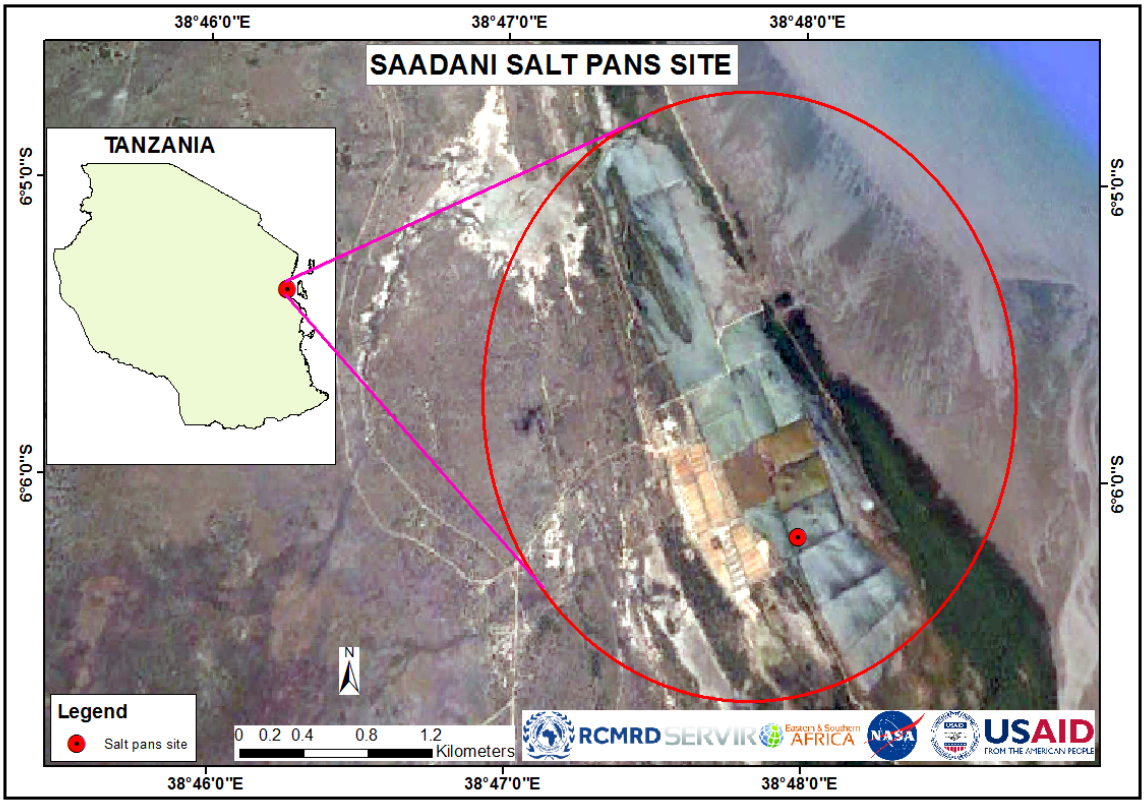

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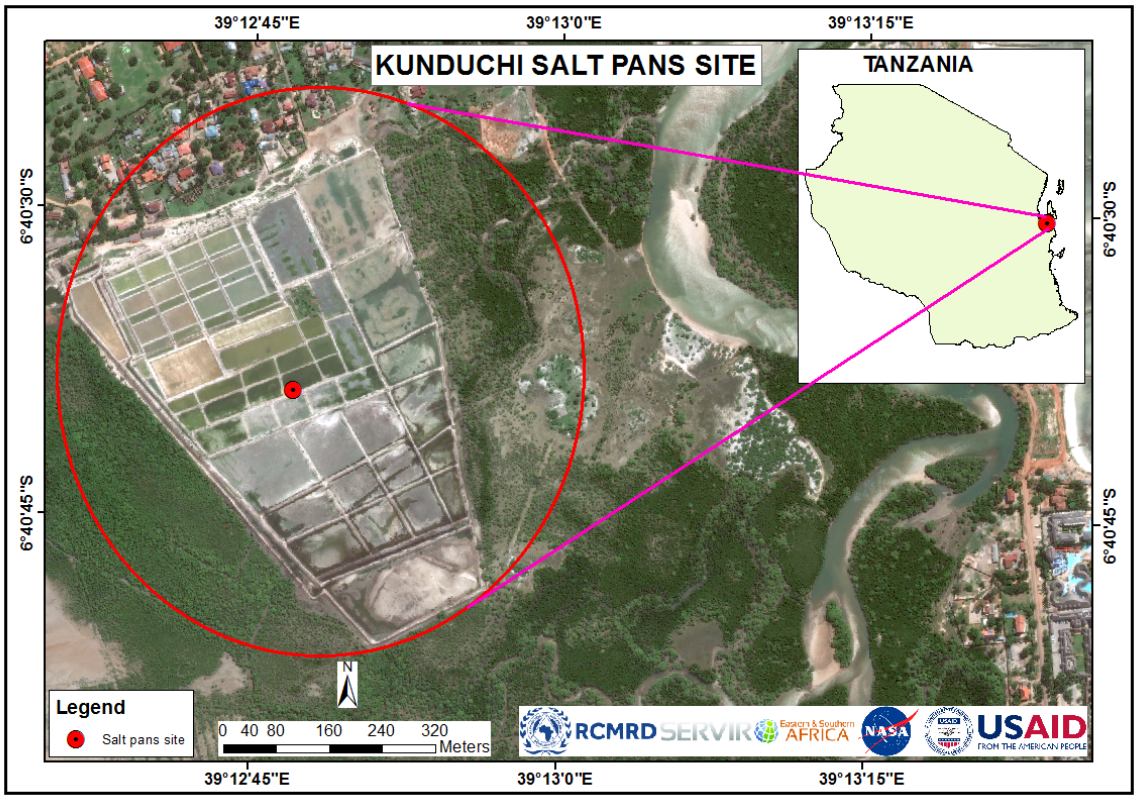

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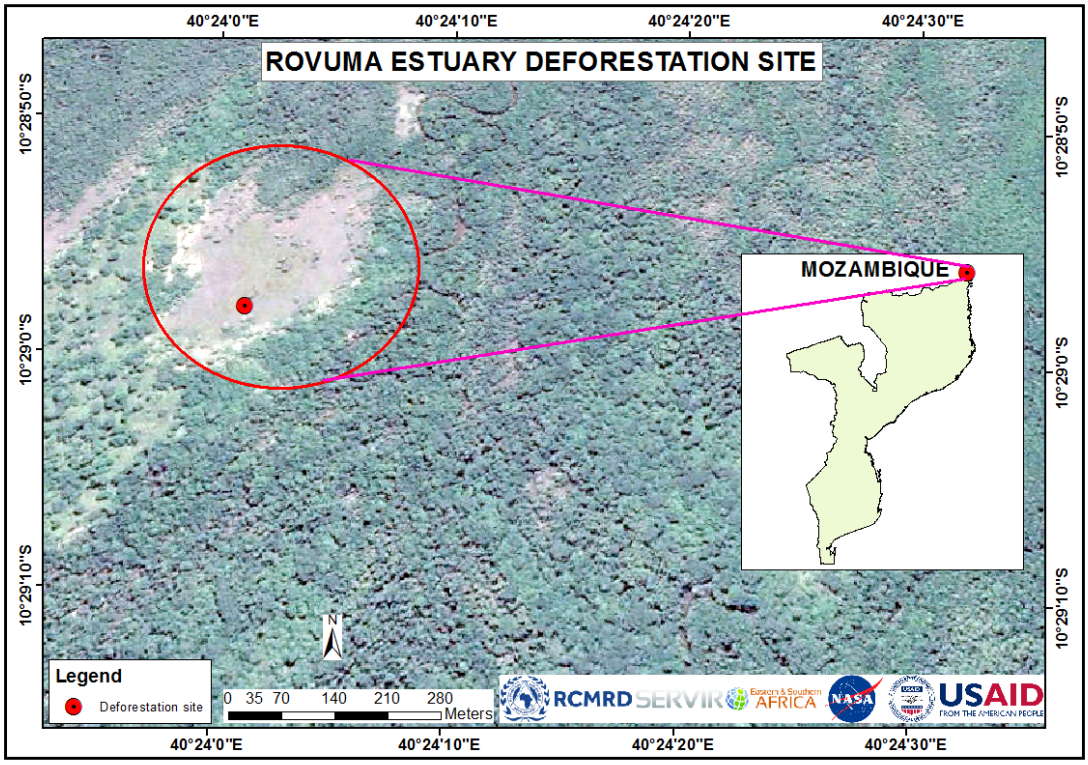
Appendix 4: Degradation hotspots maps in the Mozambique coastal zone.



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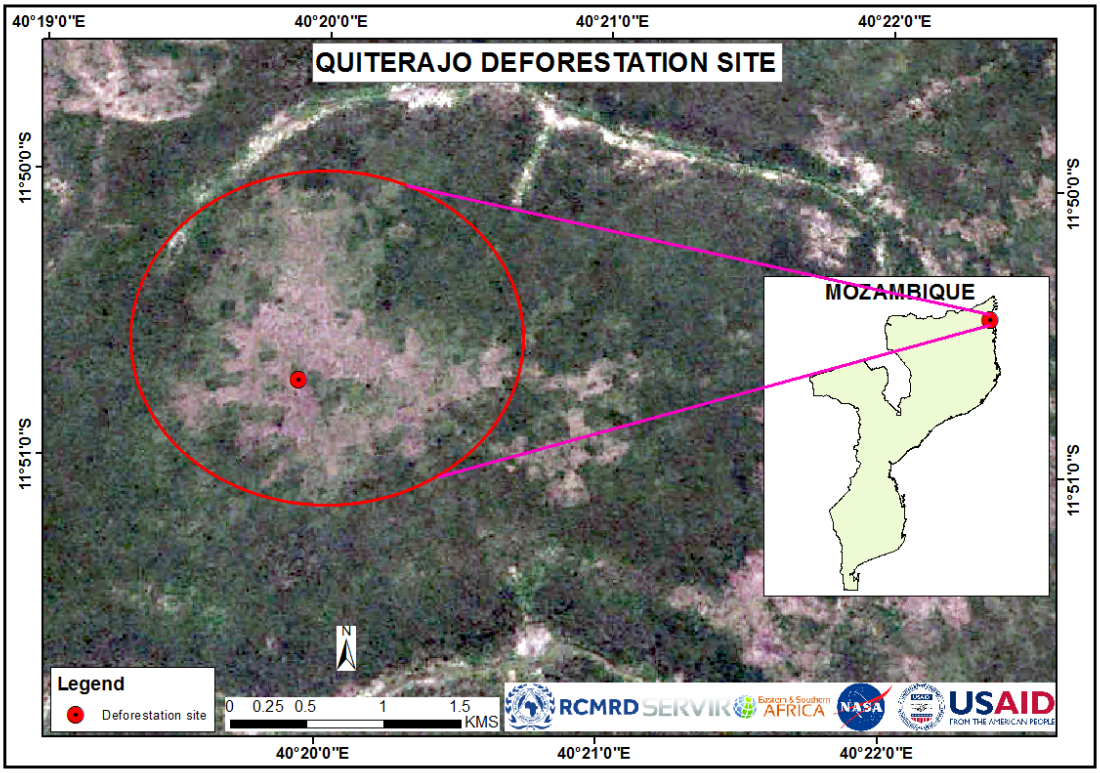

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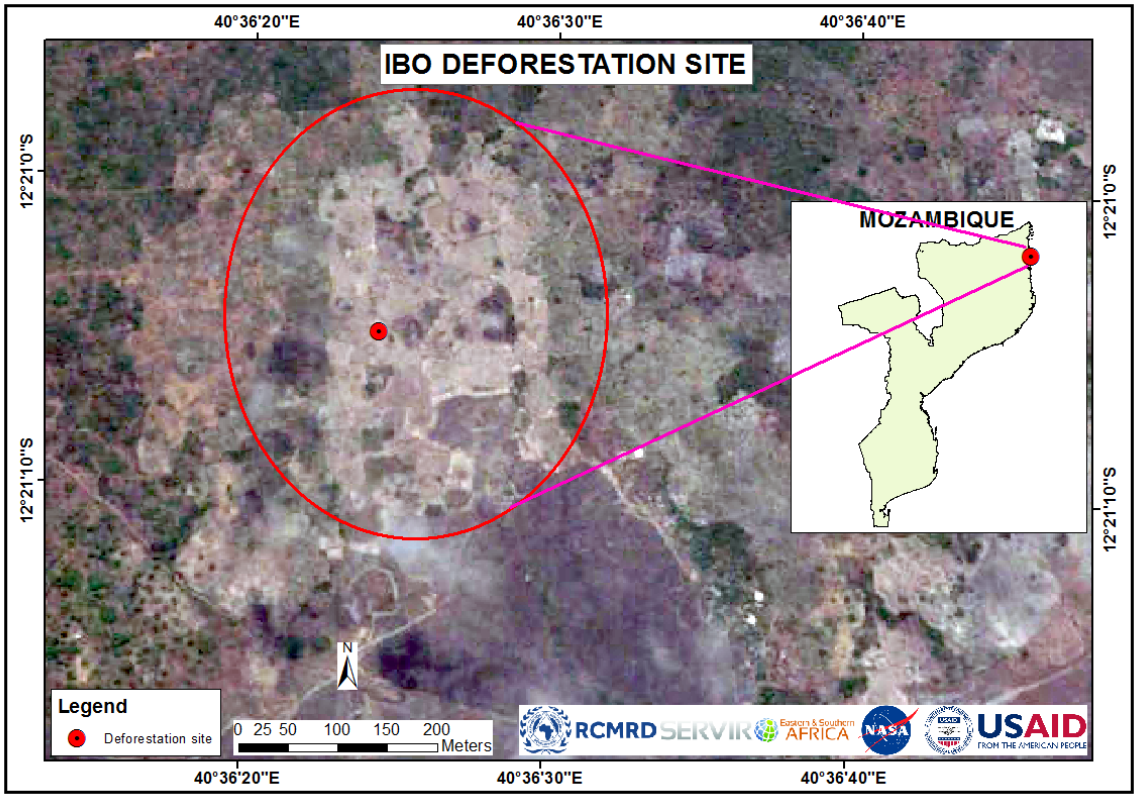

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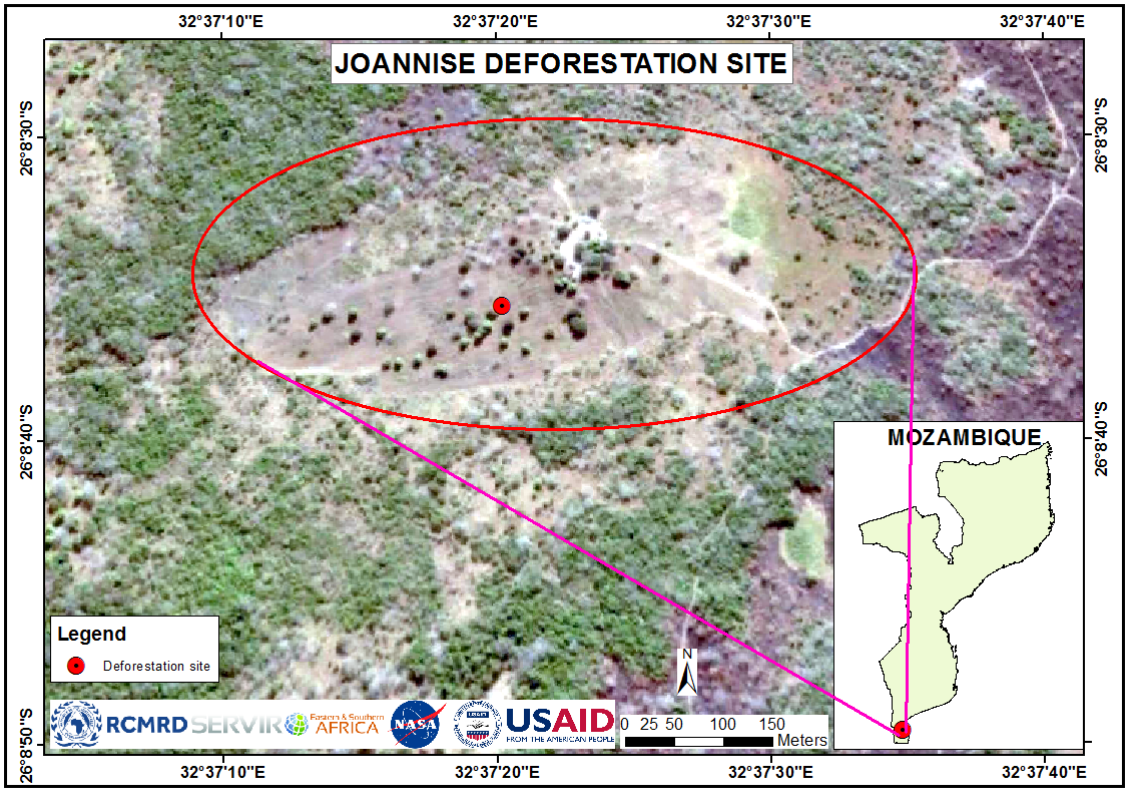

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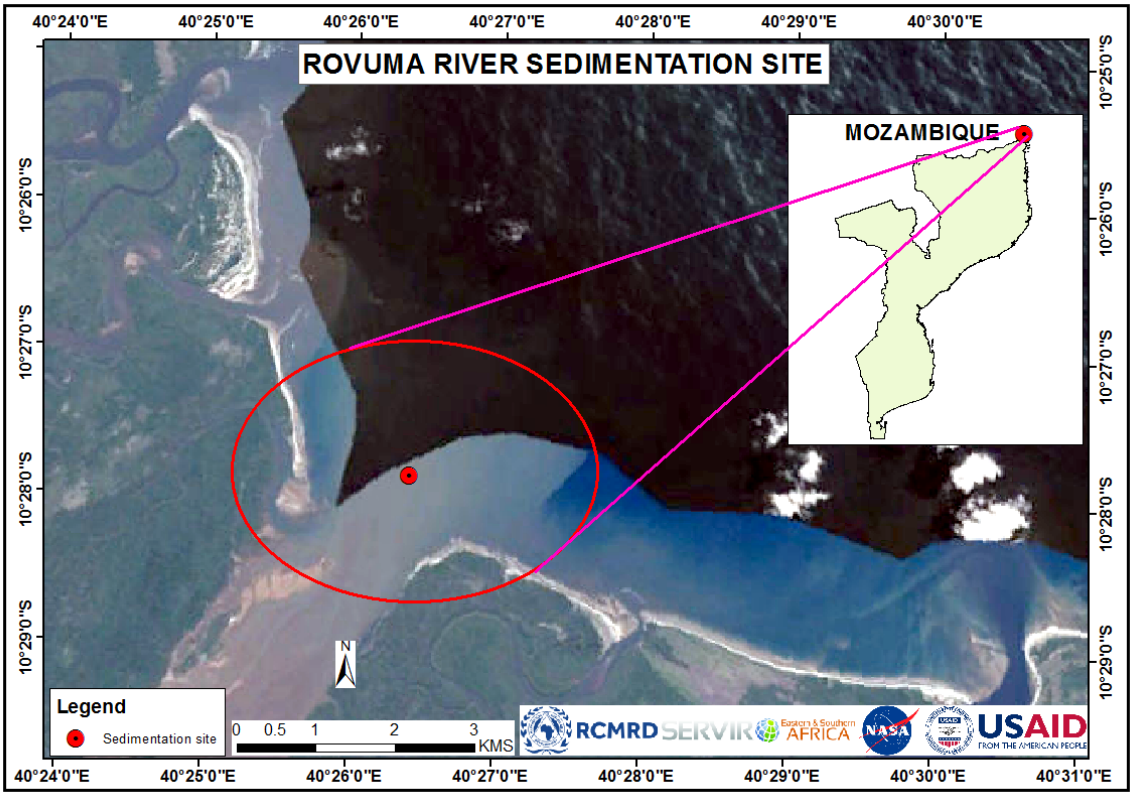

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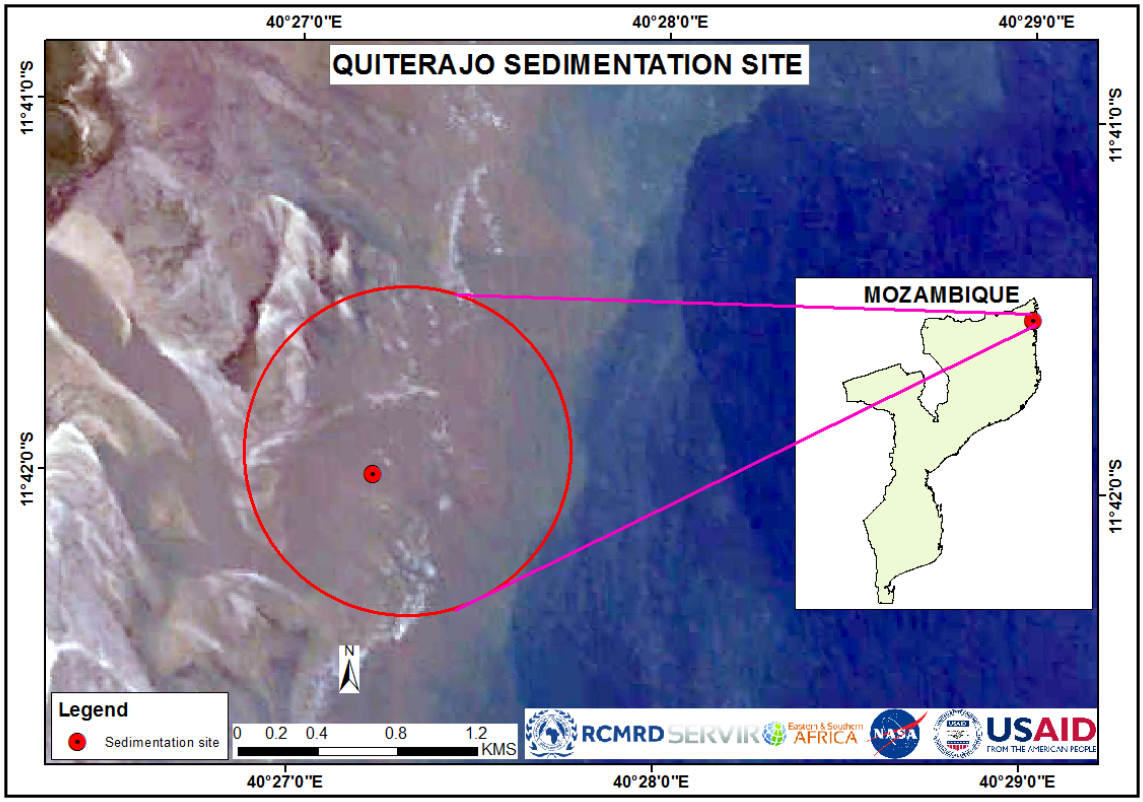

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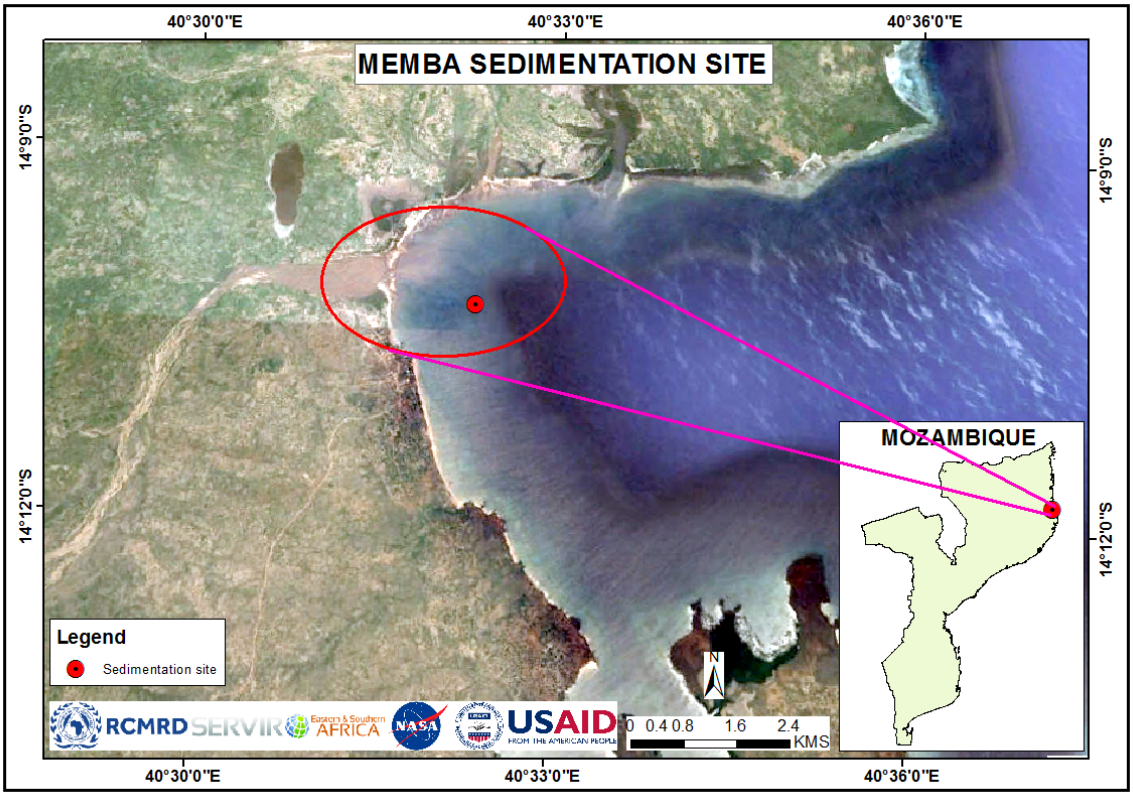

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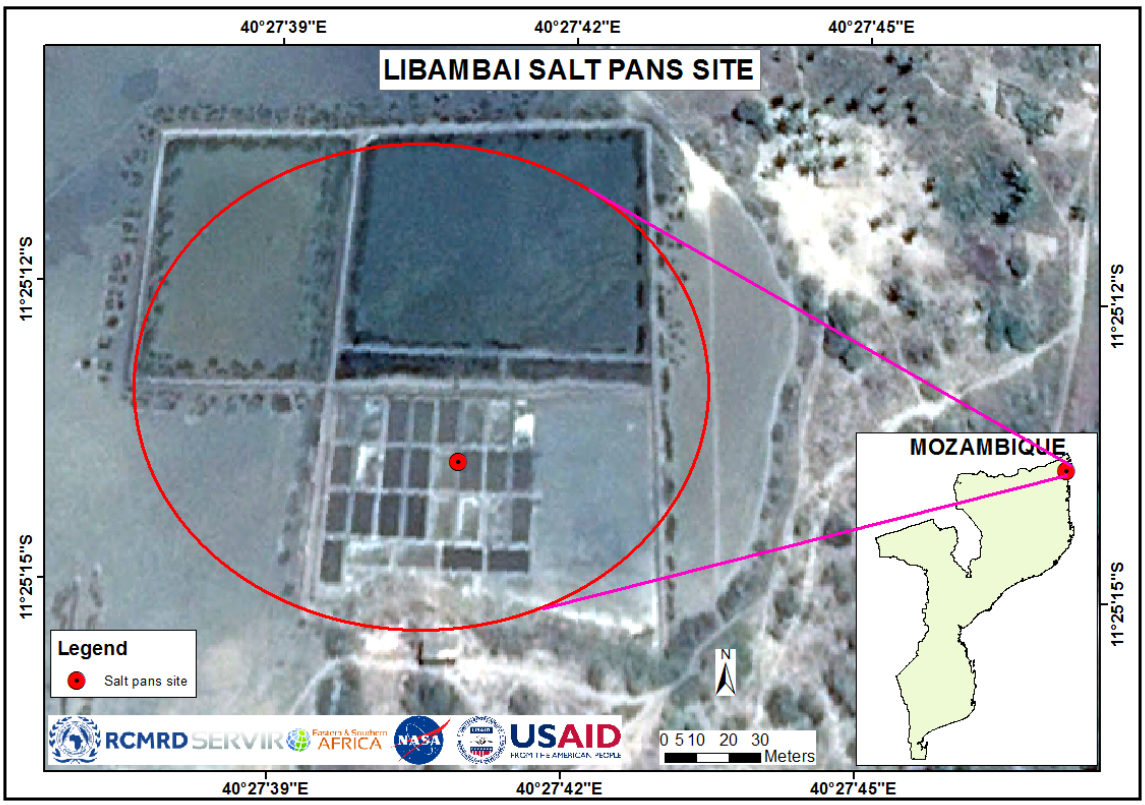

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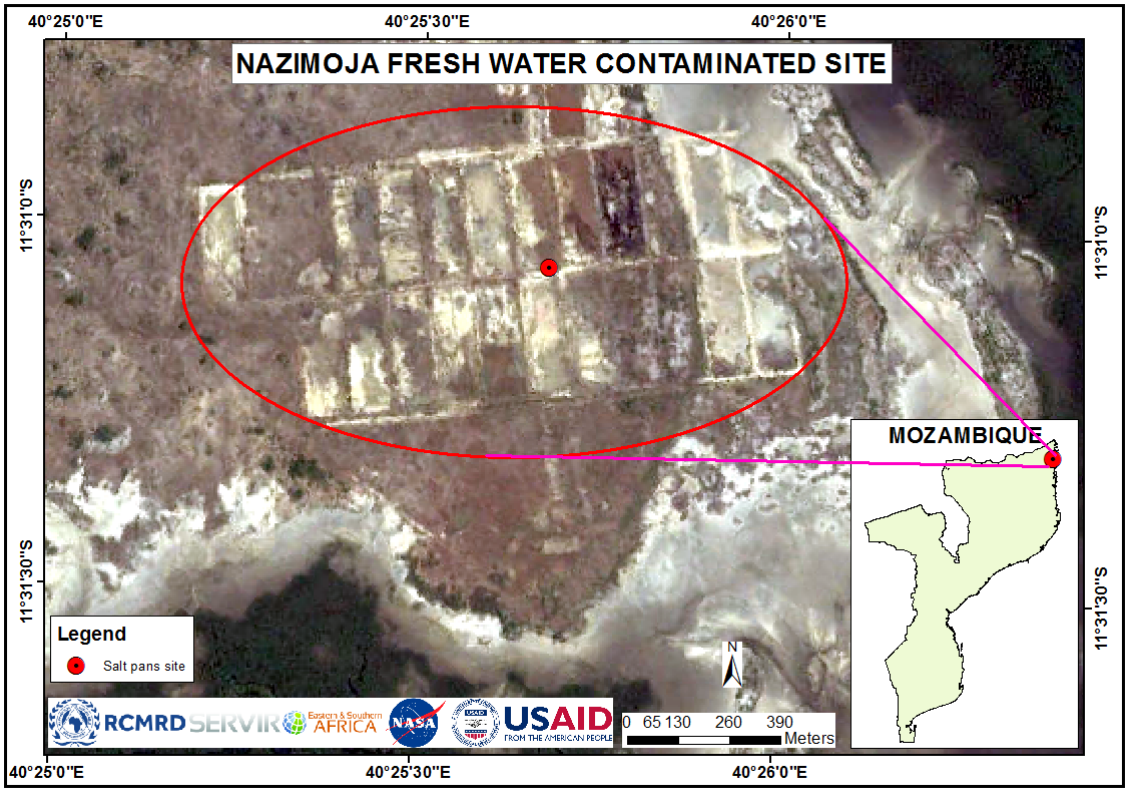

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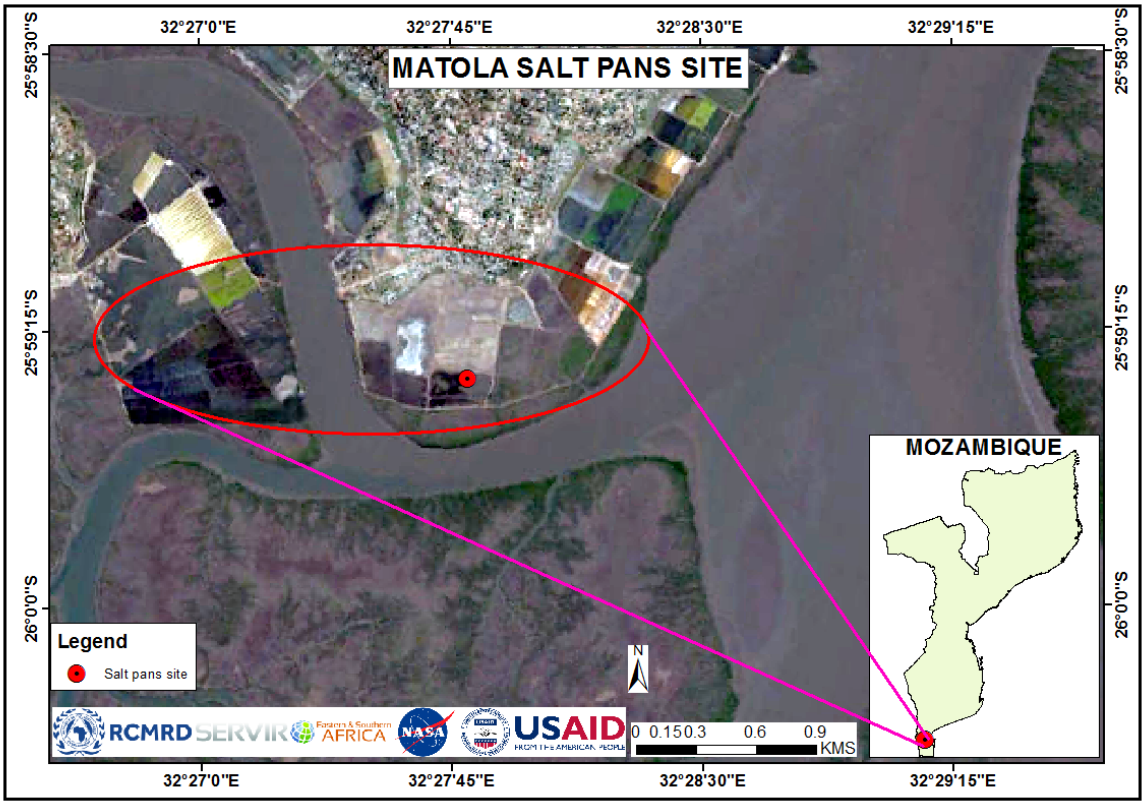

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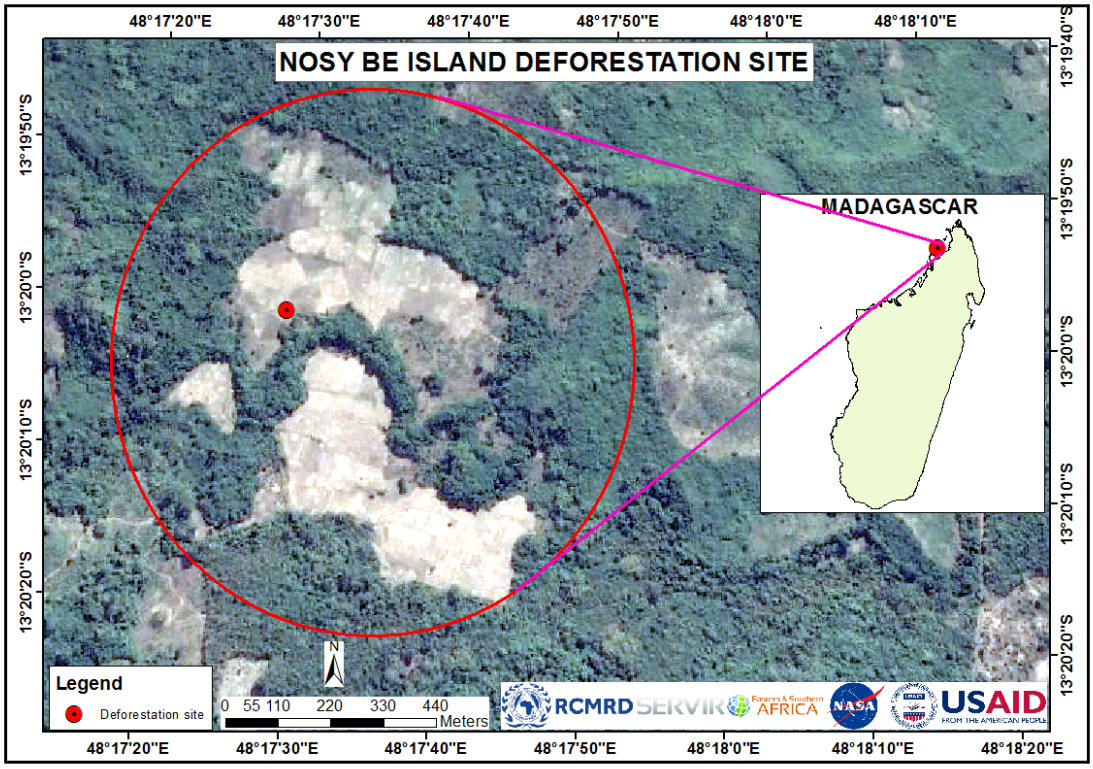
Appendix 5: Degradation hotspots maps in the Madagascar coastal zone.



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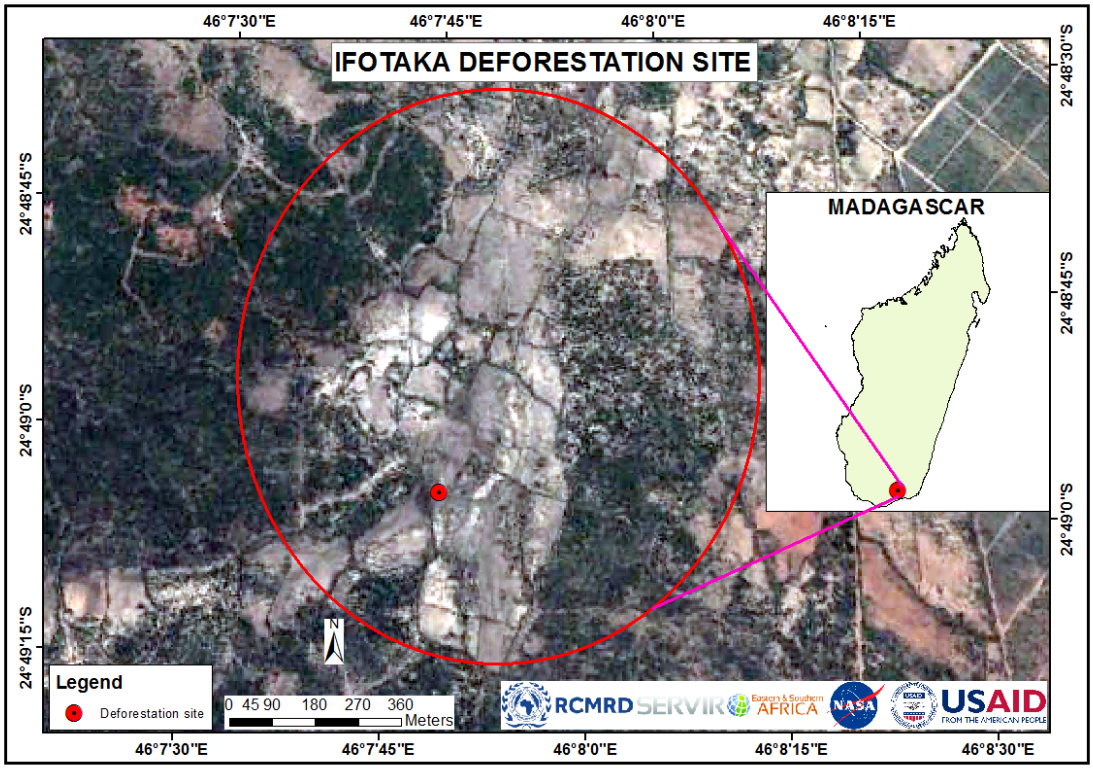

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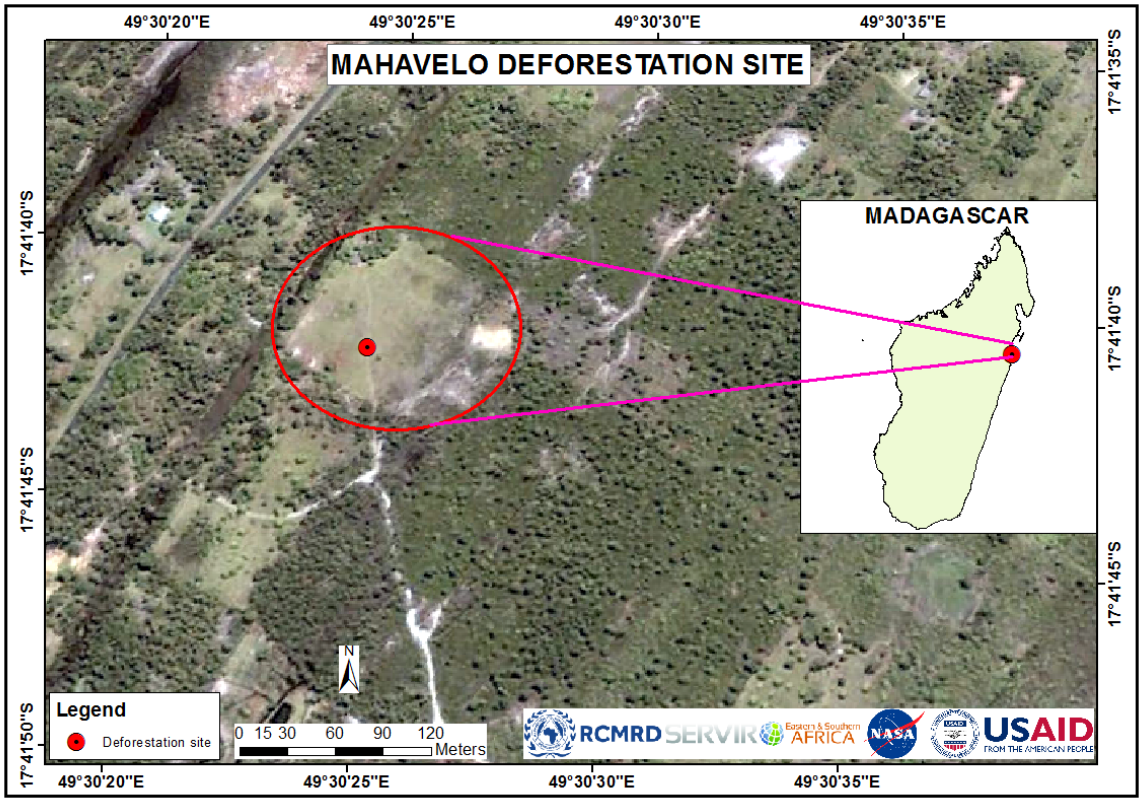

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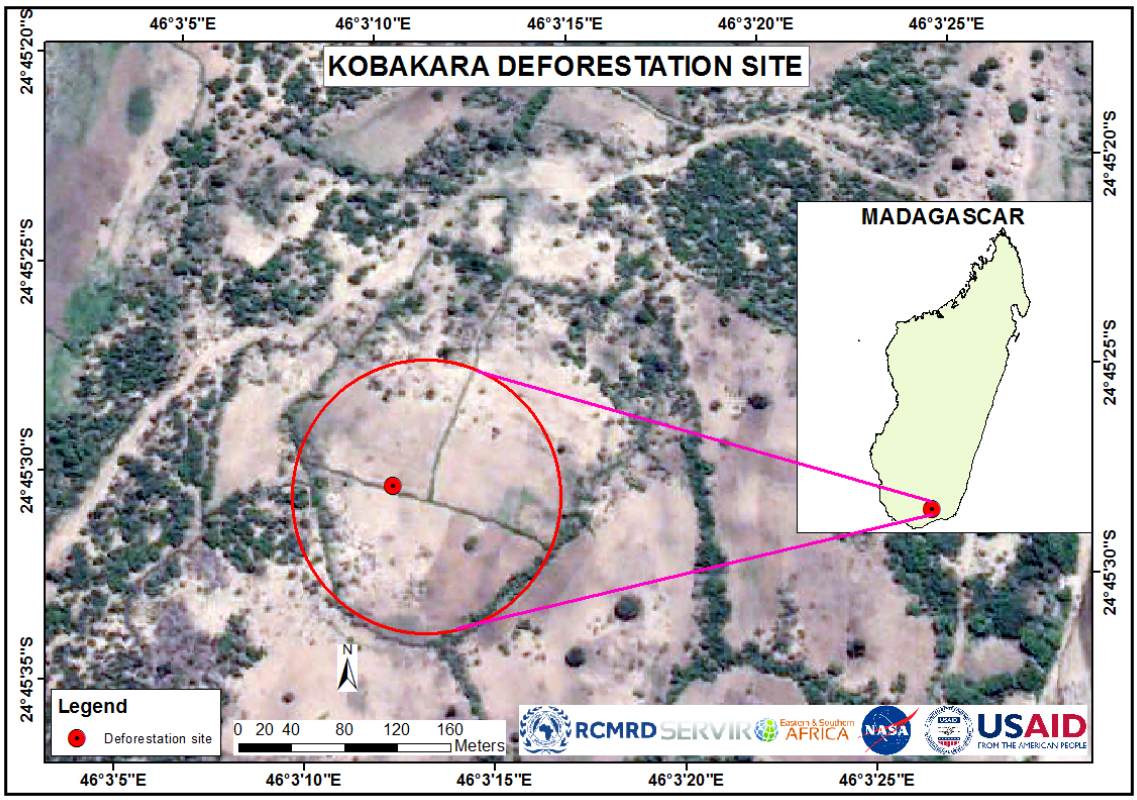

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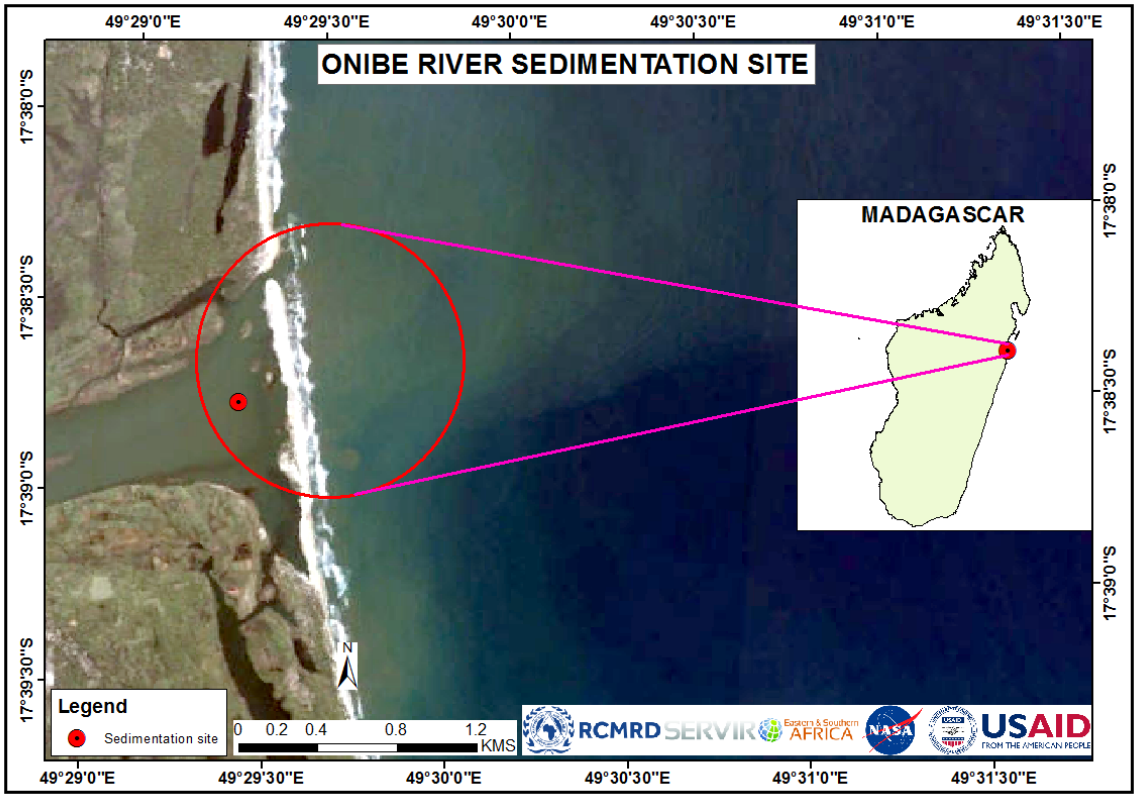

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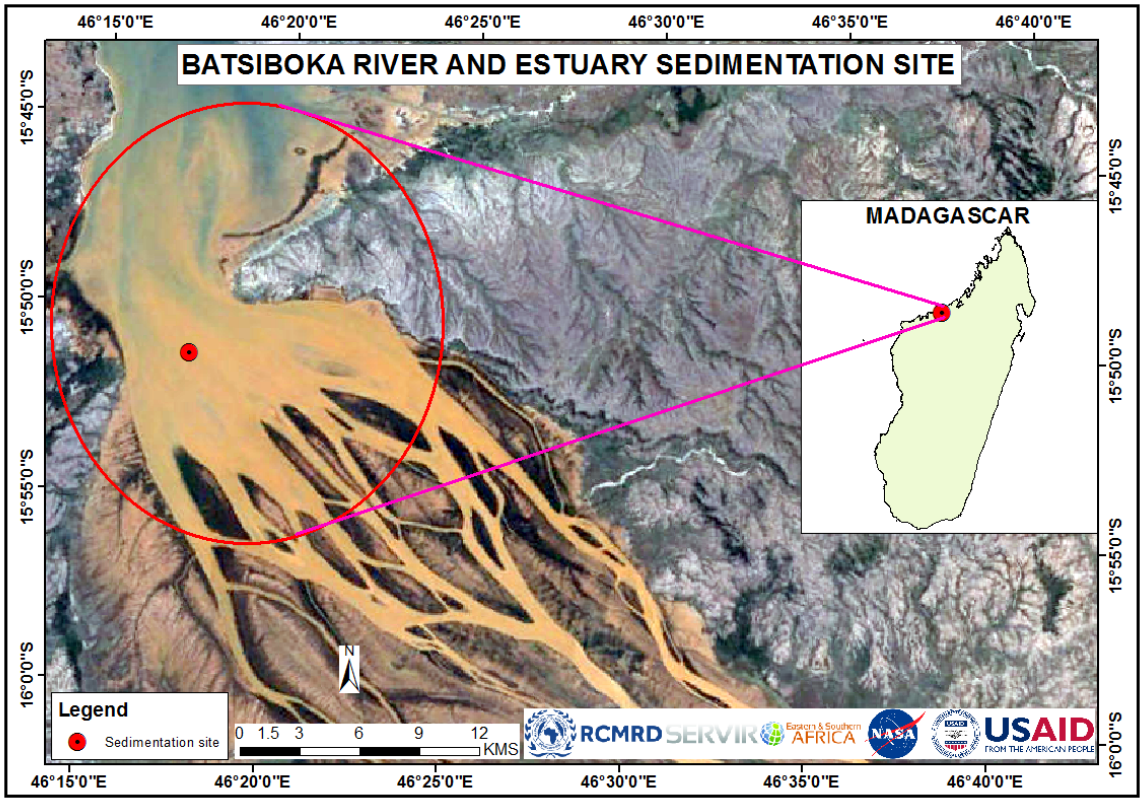

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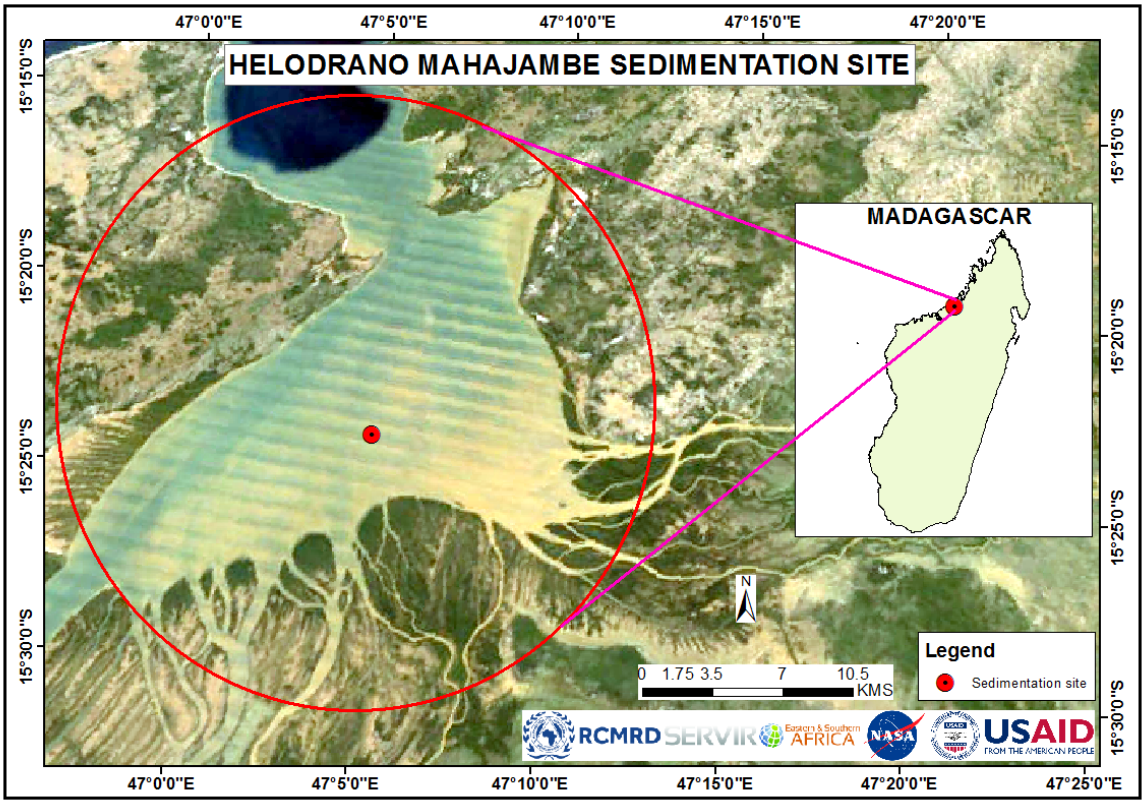

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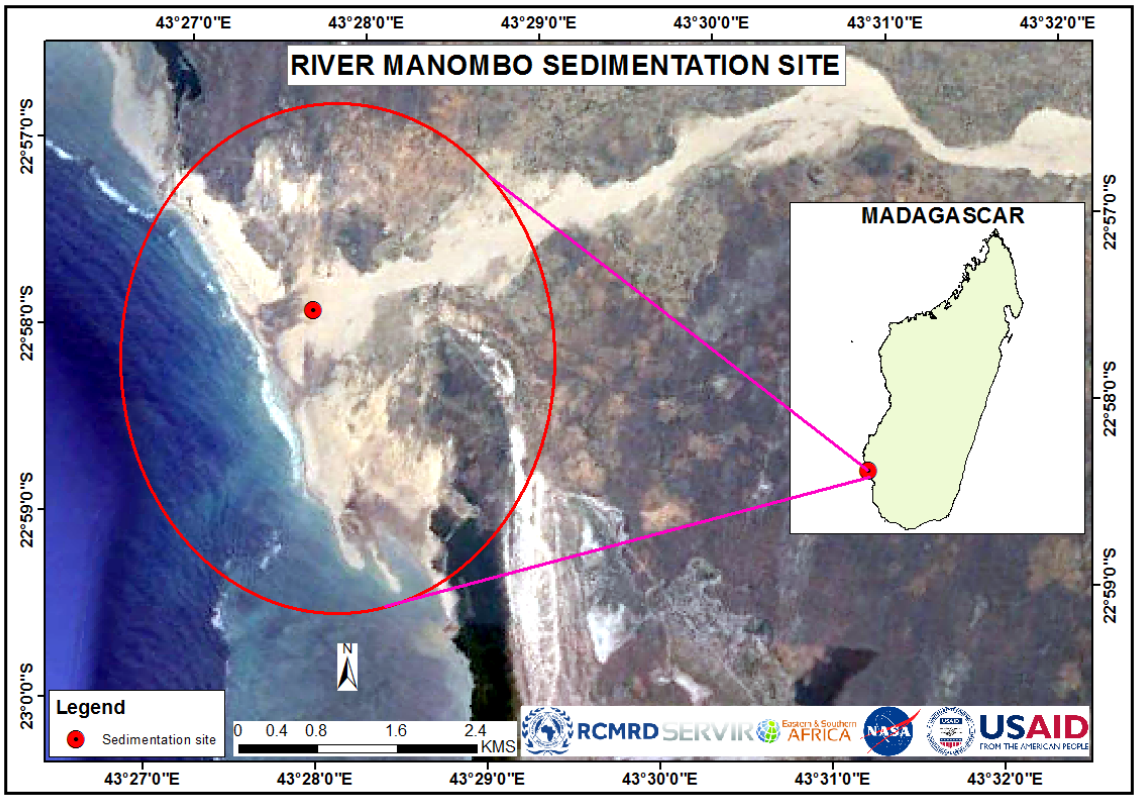

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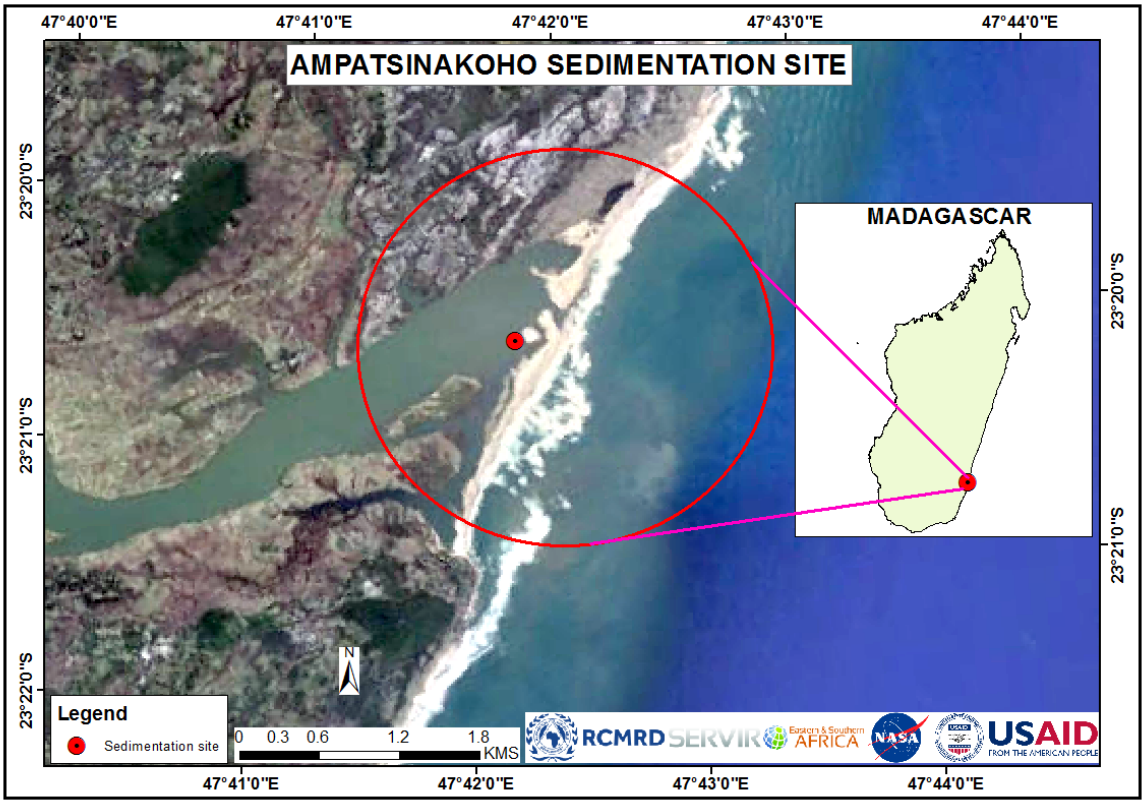

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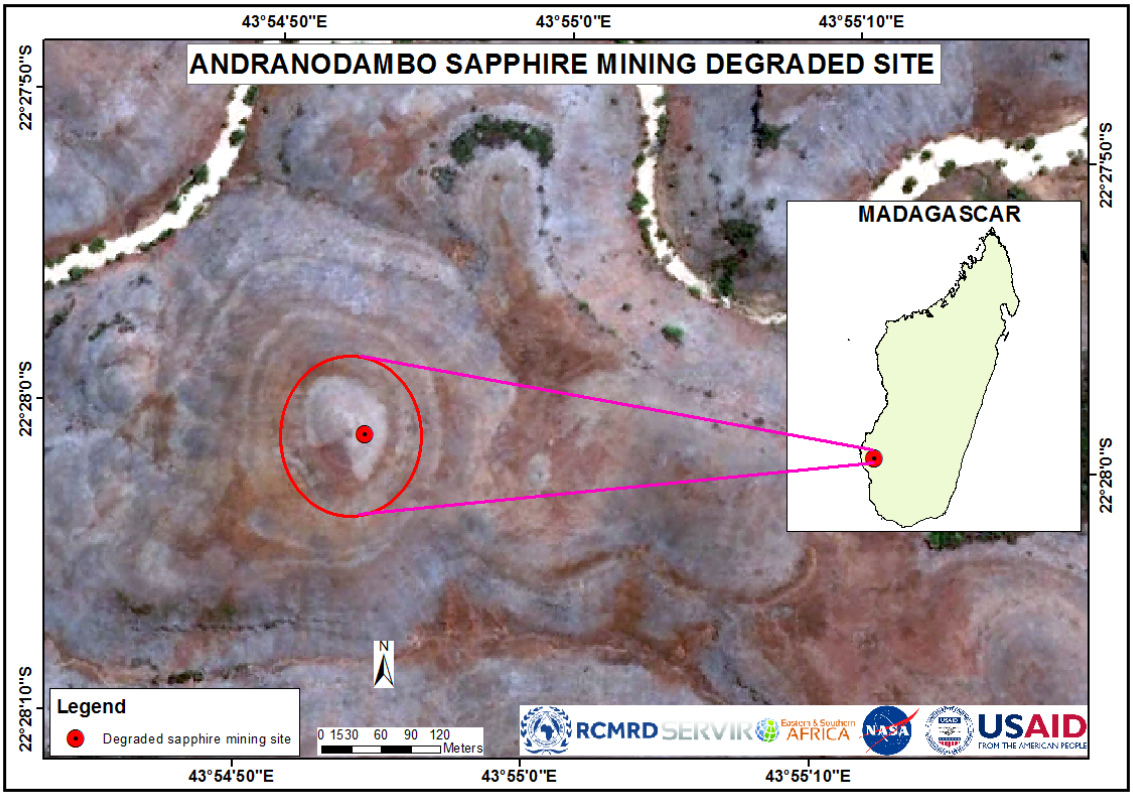

Image source: Digital Globe

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