



HUMAN ADAPTATION TO RISKY ENVIRONMENTS

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ANIMAL BIOSCIENCES STUDY PROGRAM
FACULTY OF MATHEMATICS AND NATURAL SCIENCES
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I hereby declare that dissertation entitled “Human Adaptation to Risky Environments” is original result of my own research supervised by supervisory committee and has never been submitted in any form at any institution before. All information from other authors cited here are mentioned in the text and listed in the reference at the end part of the dissertation.

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Bogor, January 2026

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RINGKASAN

YANTI ARIYANTI. Adaptasi Manusia terhadap Lingkungan Berisiko.
Dibimbing oleh TRI ATMOWIDI, BAMBANG SURYOBROTO, KANTHI
ARUM WIDAYATI, dan MICHEL RAYMOND.

Adaptasi setempat (*local adaptation*) menggambarkan proses dimana suatu organisme mengembangkan sifat-sifat yang secara khusus sesuai dengan lingkungan tempat tinggalnya. Dalam ilmu biologi, hubungan antara organisme dan lingkungan ini dapat dijelaskan melalui persamaan fundamental $P = G + E + (G \times E)$, di mana fenotipe (*Phenotype*) atau sifat yang teramati merupakan hasil interaksi dinamis antara faktor genetik (*Genotype*) dan pengaruh lingkungan (*Environment*). Seperti halnya tumbuhan dan hewan, manusia juga dapat mengembangkan adaptasi lokal terhadap lingkungan tertentu yang tercermin dalam pola perilaku, persepsi, hingga karakteristik biologis. Namun demikian, bukti ilmiah mengenai adaptasi lokal pada manusia masih relatif terbatas dan belum banyak dilaporkan dalam literatur ilmiah. Studi ini menyelidiki adaptasi manusia di gunung berapi aktif, di mana generasi bertahan meskipun menghadapi risiko bencana. Dengan menerapkan kerangka dasar biologis tersebut di atas, penelitian ini mengkaji adaptasi pada tingkat kognitif, perilaku, dan genetik di kaki Gunung Semeru (Jawa Timur, Indonesia).

Melalui eksperimen lapangan berskala besar di laboratorium alami ini, dan memanfaatkan letusan besar yang terjadi selama penelitian, kami membandingkan masyarakat yang tinggal di daerah berisiko dengan orang-orang yang tinggal di daerah yang relatif lebih aman. Hasil kami menunjukkan bahwa paparan kronis terhadap bahaya vulkanik membentuk persepsi adaptif yang unik. Penduduk di zona risiko tinggi melihat manfaat yang mengimbangi ancaman objektif. Rasionalisasi spesifik ini membentuk fenotipe adaptif mendasar, yang mengesampingkan perbedaan demografis dasar seperti jenis kelamin.

Studi ini juga menemukan bahwa paparan jangka panjang juga membentuk fenotipe perilaku yang stabil berupa kehati-hatian individu yang meningkat, sementara norma sosial-budaya seperti gotong-royong menjaga kecenderungan prososial tetap stabil. Letusan Semeru tahun 2021 bertindak sebagai katalis yang memicu lonjakan solidaritas tanpa mengubah kehati-hatian. Pola ini menunjukkan strategi adaptif ganda, karena bahaya yang terus-menerus membentuk kehati-hatian pribadi, sementara bencana yang tiba-tiba memicu solidaritas kolektif.

Analisis genetik pada gen *DRD4* yang terkait dengan pencarian hal baru, mengungkapkan gambaran yang lebih kompleks. Meskipun menunjukkan perbedaan dalam frekuensi alel antar zona, variasi genetik ini tidak terkait langsung dengan pengambilan risiko finansial dalam eksperimen. Sebaliknya, faktor seperti jenis kelamin, usia, jumlah anak, dan konteks temporal relatif terhadap letusan, menunjukkan asosiasi yang signifikan. Hal ini menunjukkan bahwa keengganan terhadap risiko yang terdokumentasi di antara penduduk yang tinggal di zona berisiko tinggi bukanlah hasil semata-mata hanya dipengaruhi oleh determinasi genetik sederhana.

Secara umum, penelitian kami menunjukkan bahwa ketahanan manusia di lingkungan ekstrem dibangun oleh adaptasi multi-level yang terintegrasi. Persepsi yang terkalibrasi secara unik memungkinkan manusia tinggal. Persepsi ini



diterjemahkan menjadi fenotipe perilaku berupa kehati-hatian pribadi yang kronis, sementara norma budaya yang mengakar seperti gotong royong (saling membantu) memastikan prososialitas yang stabil dan memungkinkan respons yang kuat dan fleksibel terhadap krisis akut. Secara keseluruhan, temuan kami menunjukkan bahwa lapisan kognitif, perilaku, dan budaya ini, yang berinteraksi dengan dasar genetik yang kompleks, membentuk model komprehensif ketahanan manusia di gunung berapi aktif.

Kata kunci: adaptasi, *DRD4*, interaksi manusia-lingkungan, perilaku, risiko vulkanik

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SUMMARY

YANTI ARIYANTI. Human Adaptation to Risky Environments. Supervised by TRI ATMOWIDI, BAMBANG SURYOBROTO, KANTHI ARUM WIDAYATI, and MICHEL RAYMOND.

Local adaptation describes the process by which organisms develop specialized traits suited to their specific environment. In biological terms, this relationship is captured by the fundamental equation $P = G + E + (G \times E)$, where phenotype (P) represents observable characteristics emerging from dynamic interactions between genetic factors (G) and environmental influences (E). Like plants and animals, humans can develop local adaptations to particular environments, reflected in perceptual frameworks, behavioural patterns, and genetical characteristics. However, scientific evidence for local adaptation in humans remains relatively limited and underreported in the scientific literature. This study investigates human adaptation to an active volcanic environment, where generations persist despite catastrophic risk. Applying this biological framework, the research examines adaptation at the cognitive, behavioural, and genetic levels on the slopes of Mount Semeru (East Java, Indonesia).

Through a large scale lab-in-the-field experiment within this natural laboratory of recurrent volcanic risk, and by exploiting an unexpected major eruption that occurred during data collection, we compared communities in the high-risk zone with those in relatively safer areas. Our findings show that chronic exposure to volcanic hazard shapes a unique adaptive perception. Residents in the high-risk zones perceive tangible and intangible benefits that offset objective threat. This context-specific rationale forms a foundational adaptive phenotype that overrides baseline demographic differences such as gender. This study also finds that long-term exposure shapes a stable behavioural phenotype of increased individual risk aversion, while socio-cultural norms such *gotong-royong* (mutual assistance) maintain stable prosocial tendencies. The 2021 Semeru eruption acted as a temporary catalyst, triggering a surge in solidarity without altering this underlying caution. This pattern demonstrates a dual adaptive strategy, where persistent hazard shapes personal caution, while sudden catastrophe triggers collective solidarity.

Genetic analysis of the *DRD4* gene, associated with novelty seeking, reveals a more complex picture. Although allele frequency differences were observed between zones, this genetic variation was not directly linked to financial risk taking in experiments. Instead, factor such as gender, age, number of children, and temporal context relative to the eruption showed significant associations. This suggest that the well-documented risk aversion among high-risk zone residents is not driven by simple genetic determinism.

Overall, our study demonstrates that human persistence in extreme environments is built through integrated multi-level adaptation. A uniquely calibrated perception of the landscape enables habitation, which translates into a chronic personal caution phenotype, while deeply rooted cultural norms like *gotong royong* ensure stable prosociality and enable a strong, flexible response to acute crises. Together, these cognitive, behavioural, and cultural layers, interacting with

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a complex genetic basis, constitute a comprehensive model of human resilience on an active volcano.

Keywords: adaptation, behaviour, *DRD4*, human-environment interaction, volcanic risk

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HUMAN ADAPTATION TO RISKY ENVIRONMENTS

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Dissertation
submitted in partial fulfillment of the requirements for
Doctoral Degree
In Major of Animal Biosciences

**ANIMAL BIOSCIENCES STUDY PROGRAM
FACULTY OF MATHEMATICS AND NATURAL SCIENCES
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FOREWORD

I embarked on a voyage to understand risk, only to discover I was both the sailor and the sea. “Human Adaptation to Risky Environments” is the artifact of this realization, a testament to the profound truth that to study a phenomenon is, inevitably, to become its subject.

No sailor navigates uncharted waters alone. For the charts, the stars, and the steady hands that guided this vessel, I am profoundly grateful. Words cannot express my gratitude to my supervisory committee: Prof. Dr. Ir. Tri Atmowidi, S.Si., M.Si., Dr. Drs. Bambang Suryobroto, Prof. Michel Raymond, PhD, and Dr. Kanthi Arum Widayati, S.Si., M.Si. Their guidance at every step of this research has been invaluable, and without them, this work would not have been possible. I also extend my sincere thanks to Prof. Marc Willinger and Clement Mettling, PhD, for providing me with the opportunity to learn new perspectives on risk behaviour from both economic and molecular genetic points of view. My sincere thanks also go to those who provided kindness and support during my lab work in Montpellier: Dimitri Dubois, Valérie Durant, Gabriel Bayle, Yujiang Sun and Sarah Feti.

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I hope you enjoyed reading this work!

Bogor, January 2026

Yanti Ariyanti



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