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The calamity of eruptions, or an eruption of benefits? Mt. Bromo human-volcano system a case study of an open risk perception

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Abstract

In this paper we investigate the question not of *how*, but *why* people actively choose to live with continued exposure to considerable hazard. A field survey of the human volcano interaction at Bromo volcano was based on semi-structured interviews and focus group discussions. The recorded interviews were transcribed and analysed according to recurrent themes in the answers. The facts found from the field investigation were then confronted with the previous existing concepts. The result shows that the interaction between human and volcanic environment at Bromo volcano is multifaceted and complex. The Tengger people choose – rather than being forced – to live with volcanic hazards because they are not only exposed to its negative consequence, but also enjoy benefits and opportunities of physical, spiritual and socio-cultural nature that arise within the human-volcanic system. Following this perspective, the concept of risk itself must be revisited and expanded from a one-sided focus on hazardous processes to a more holistic view of risk that includes the various positive aspects that pertain to the entire system. The development of a generic human-volcanic system model could provide the basis for the development of an open risk concept.

1 Introduction

Volcanic activities almost invariably affect human lives. More than half a billion people live in the direct vicinity of volcanoes and are thus exposed to hazard (Tilling, 2005). At the same time often places not only of serene beauty, but abundant with diverse natural resources, are located adjacent to highly active volcanic zones. Indonesia, situated at the intersection of three active tectonic plates (the Eurasian, Australian and Pacific plates), at the aptly named *ring of fire*, boasts 129 active volcanoes and 271 eruption points (Abidin et al., 2004, Pratomo, 2006; Zaennudin, 2010) (Fig. 1). Approximately 3.3 million people in Indonesia live in areas categorized as volcanic regions (CVGHM, 2010). In Java Island, where 120 million people live in the shadow of 30 volcanoes

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more than 140 000 fatalities occurred due to volcanic eruptions in the last 500 years (Surono, 2013).

With its periodical eruptions Mt. Bromo on Java Island is one of the most active volcanoes in Indonesia. The communities living around the mountain have evolved a unique culture that is inspired by the volcano as central symbol and deity. The *Tenggerese* are even named after the ancient Tengger Caldera, which today contains Mt. Bromo. They count approximately 600 000 and are descendants of the Majapahit Princes of Java. As observed elsewhere around the world and throughout history (Duncan et al., 1981; Fisher et al., 1997; Heijmasn, 2001; Kelman and Mather, 2008) even severe eruptions like those of Mt. Bromo in 2010 have not deterred people from returning and continuing to live with a considerable risk of hazard. Despite suffering from devastating impacts of volcanic eruptions people decide to live and adapt to the recurring phenomenon.

The initial surprise these latter statements may cause – people choosing to live with objective danger – follows the classical deterministic scientific approach with a clear focus on the volcano, its hazards and related potential negative impacts on society (Siswowidjoyo et al., 1997; Itoh et al., 2000; Andreastuti, 2000; van Rotterdam-Los et al., 2008; De Bélizal et al., 2012; Mei et al., 2013). Two aspects have to be highlighted here: (i) from a theoretical point of view, volcano and human society are conventionally understood as two dichotomous systems, a relationship where the volcano and its activities determine societal behaviour distinctly; (ii) the focus of such an approach lies on investigating the negative, threatening impacts of a volcano on society and how people live and cope with this situation.

We want to question here whether this deterministic view bears any merit and produces any progress in terms of (a) deeper system understanding and (b) application in disaster risk management at all. In recent decades, on both the theoretical as the practical side a change in thinking has occurred. Based on discourses from ancient until modern philosophers and intellectual pioneers, the relation between humankind and nature, respective society and environment (see e.g. Descartes, 1641; Popper, 1972; Latour, 1993; Zierhofer, 2002), give preference to the idea of Earth being a

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human-environment system, where society and nature are inseparably interlinked by manifold processes (see e.g. Fischer-Kowalski and Weisz, 1999; Wardenga and Weichhart, 2006). Besides these theoretical reflections, it was indeed very application-driven research that concluded that all grand global challenges (e.g. climate change, resource scarcity, globalisation) can only be understood and targeted solution can only be tailored when there is a holistic view on society and nature. The earth system must be understood as a human-environment system where both sides are driving and driven at the same time.

As a consequence, in this paper we do not investigate the question of *how*, but *why* people live with continued exposure to considerable hazard. Expanding upon the previously proposed explanations that this behaviour is due to a lack of hazard knowledge (Gregg et al., 2004; Bird et al., 2010), a lack of alternatives (Wisner et al., 2004; Lavigne et al., 2008), or that people may be forced to do so based on their marginalized social status (Bryant, 1998), we propose that risk perception and risk tolerance can only be fully understood when investigating within a framework of a human-environment system in general, and a human-volcano system in specific.

The human-volcano system that we present here allows for an analysis that goes beyond the narrow focus of volcanic eruptions and lends itself for a more holistic appreciation of volcanic risk as presenting both, hazards and opportunities. Based on a case study from Mt. Bromo, we will highlight the need to revise common risk concepts and to include the assessment of upside risks, or opportunities, that may off-set exposure to negative effects. We will conclude that an open risk concept is not only necessary to understand decision making processes, but will have deep implications for disaster risk reduction and risk management strategies in the context of volcanism and for their general progression. In order to gain a comprehensive understanding of the natural and societal ramification of living with volcanic hazard risk, we will first lay out the physical characteristics of eruption activity of Mt. Bromo and then contextualize this within a human-volcano system approach.

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2 Mt. Bromo characteristics and eruption activity

Mt. Bromo (2392 m) is shared by four districts in East Java Indonesia, namely Probolinggo, Malang, Pasuruan and Lumajang. Mt. Bromo is an active volcano located inside the much larger and older Tengger caldera. The diameter of the caldera is 9 km stretching from North to South and was formed by the ancient Tengger Volcano during the late Pleistocene and early Holocene (Gerven and Pichlert, 1995; Solikhin et al., 2012). Widely distributed sand deposits make for the famous Sand Sea caldera (Fig. 2). The frequent eruption activity of Mt. Bromo is well recorded. Data shows that Bromo erupted at least 56 times since 1804, ranging from mild to moderate eruptions with duration between 1 and 270 [sic] days (Fig. 3) (CVGHM, 2010). According to CVGHM, Bromo volcano is an active volcano which erupted many times on a scale of VEI (Volcanic Eruption Index) level 2.

The last eruption of Mt. Bromo in 2010 was unusual as it continued for nine months, the longest period in its recorded history (Bachri et al., 2013a). The eruption type had changed from previous Vulcanian type to Stromboli type activity. These were phreatomagmatic eruptions, producing materials dominated by ash and sand. The first eruption occurred on 20 November 2010 with the volcanic plume reaching a height of 250 m. On 23 November a second, larger eruption followed. During this period, the height of the volcanic ash plume ranged from 400 to 1000 m covering the entire Bromo area (Table 1). By December 2010 volcanic ash precipitated in tens of kilometers throughout the northern, eastern and southern direction of Mt. Bromo area. During the following nine months volcanic material such as ash and rough sand could be found 50 km from Mt. Bromo. Volcanic ash also reached Surabaya city, located 90 km from the crater. Furthermore, volcanic bombs with sizes of 1–3 cm impacted up to a distance of 2.2 km from the crater.

The total economic loss due to the 2010 eruptions amounts to more than 154 Billion IDR (~ USD 15.5 Million) reflecting the severe affects in agriculture, tourism activity and loss of property (BPBD, 2011). Indirect and difficult to monetize impacts also caused a

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decline in the water availability, disrupted electricity supply and transportation, diminished trading activity and lead to health problems. A total of 70 000, mostly agriculture-dependent people distributed over 33 villages were affected by Mt. Bromo's eruptions (BPS, 2011). The 2010 eruptions were the worst ever recorded eruptions of Mt. Bromo and among the most severe volcanic eruptions in recent history worldwide.

3 Materials and methods

In order to reach a comprehensive understanding of human-volcano interaction, this study bridges between natural and social science. Thereby the scope of our research objective that includes physical and social aspects is reflected in both, research methodology and style of analysis, which lends from physical-geographical discussion as well as ethnographic observations. In researching the human-volcano interaction within the Bromo region this study draws on (1) existing statistic data of the research area (2) semi-structured interview and (3) focus group discussion. The first phase of the field work was held in February–March 2012 with the purpose to capture data related to Bromo volcano. The second phase of field work (July–August 2012) involved semi-structured interviews with key persons at the village level and during the third phase focus group discussion were held in February–March 2013. While the secondary data collection includes quantitative aspects, the main focus of the field research was qualitative in nature.

– Existing statistic data of the research area
  For an analysis of the environmental condition of Bromo volcano and in order to profile adjacent communities we compiled various data sets. The eruption monitoring data and volcanic hazard maps were obtained from the Center for Volcanology and Geological Hazard Mitigation (CVGHM). Data related to damage and loss assessments (DALA) were collected to examine eruption impacts both on physical and societal environment of each village with particular focus on the 2010

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Bromo eruptions. This data was kindly supplied by the regional disaster management agency (*Badan Penanggulangan Bencana Daerah-BPBD*) of Probolinggo city, East Java Province. During data collection also keys informants and communities at risk were profiled and identified through abstracting data from demographic statistics at the village level.

– Semi-structured interviews with key informants
During July-September 2012 we conducted semi-structured interviews with local communities and government officials in four districts (Pasuruan, Probolinggo, Malang and Lumajang) surrounding Mt. Bromo in order to examine the human-volcano relationship within the Bromo area in general and investigate local knowledge related to hazard, risk perception and adaptation strategies in specific. Only such villages were considered which were according to the secondary data information exposed to the eruption. Interviews took place in two villages in Pasuruan (Wonokitri and Tosari), four villages in Probolinggo (Ngadirejo, Ngadisari, Wriningan om, Sumber), one village in Malang (Ngadas) and one village in Lumajang districts (Ranupane) (Fig. 4). Altogether 13 interviews were conducted with the informants being village officers, farmers, teacher, dukuns and three authorized staff from BPBD Probolinggo city and CVGHM (Table 2). Interviews were loosely structured starting from the physical impacts to social effect. However, the informants were encouraged to answer freely as not to be limited to the guiding question (Table 3). The objective was to initiate various members of the Bromo community (*The Tenggerese*) to share their experience of Mt. Bromo in an unbiased way and deliberately without exclusive focus on eruptions or negative impacts only. Discernible from Table 3 question that could directly lead toward positive and negative answers were avoided. Questions pertained to hazard understanding, familiarity with volcanic risks and dread factors as well as on the opportunities provided by Mt. Bromo and the general attitude towards the volcano and its role in local culture. All interviews were shaped to the local context and

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were conducted in Indonesian and Javanese language. Interviews were recorded by video recorder.

– Focus Group Discussion (FGD)
Following the semi structured interviews of phase I and II of the field work we conducted a Focus Group Discussion in phase III. With the FGD we hoped to gain deeper insights by giving the participating group an opportunity to express themselves in their own words and confront and compare their individual perceptions among other members of the community. We chose the community of Ngadijero for the FGD, since our analysis of phase I and II showed that this village was most negatively exposed to the recent eruptions. The discussion was initiated with similar questions as were used to structure the interviews in phase II (Table 3). There were eight participants to the FGD consisting of farmer, village official, village head and young representative (Table 2).

Semi-structured Interviews and Focus Group Discussion were transcribed and analysed according to recurrent themes in the answers. Furthermore, all these themes will correlate to one another in order to obtain comprehensive descriptions about people's perception of living with Mt. Bromo. The facts found from the study is expressed in narrative form and analysed in view of existing research of habitation in volcanic areas as well as prevailing concepts of risk research in general.

4 Towards a human volcanic system – the case of Mt. Bromo volcano

In the following paragraphs we present the results of our findings on the interaction between volcanic eruptions, local knowledge and risk in our study area in form of a human-volcano system under Bromo's VEI level 2 (Fig. 5). Therein the various interactions between community and volcano are shown. Both, physical and social aspects are considered.

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4.1 Environmental condition (Bromo volcanic eruption in 2010)

The four major hazards produced by Mt. Bromo in 2010 were tephra fall/ballistics, volcanic mud flow, landslides and gas emission. Form and impact from these sources of hazards varied from negligible to severe. Tephra fall comprised volcanic ash, angular blocks and rounded bombs (see Fig. 5). Areas inside the Tengger caldera were exposed to angular blocks > 64 mm and rounded bombs > 64 mm (Zaennudin, 2011). In addition, volcanic ash with grain-sizes of 2–64 mm was distributed throughout the surrounding area depending on wind direction, morphology and weight of the material. For instance, regions with an elevation over 2000 msl were relatively safer from volcanic ash due to the protection by the caldera wall (Bachri et al., 2013b). Ngadirejo as a village which located in this categorized always effect by eruption, this also verified by 13 interviewed people at village level and three authorized staff from BPBD Probolinggo city and CVGHM.

Areas covered by volcanic ash and fine rock material could not be planted with several crop types including potatoes and vegetables until two years after the eruptions. In the focus group discussion, farmers participant describe that this condition also caused by the position of land which sometime located in the flat area make volcanic material cannot be easy swept by the run off. However, areas which were covered by ashes without fine rock material were more fertile after one year from the time of eruption. Local communities were well aware of both the negative and positive effects on agricultural productivity. They referred to the increase of soil fertility as *Berkah Bromo* or Bromo's opportunity. Most of interviewed people particularly farmer stated that Bromo provides benefits for the continuity of their life.

Additional to the direct hazards from eruptions Mt. Bromo also generated secondary hazards such as volcanic mud flow (see Fig. 5), locally known as "*lahar hujan*" (lava rain). Particularly areas located at the foothills of the volcano were affected by this source of hazard. More than 20 houses collapsed due to "*lahar hujan*" (Bachri et al., 2013a). Heavy rainfall and large materials deposited from Mt. Bromo caused the "*lahar*

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hujan" to collapse as well as flooding of the river Badesh. As result of the floods a number of buildings on the riverbanks were destroyed. Furthermore, agricultural land was degraded by "*lahar hujan*". Despite the negative effects of "*lahar hujan*" in the short term, an increased agricultural productivity of the affected land can be observed and is appreciated as well as capitalized on by local people. *Bapak* Kirno (all names were changed to protect the informant's identity), Head of Village (58), from Wrininganom Village informs us that:

"Wilayah yang terkena banjir lahar material bromo akan menjadi lebih subur setelah beberapa lama apabila kandungannya pasirnya tidak dominan" (transl.:"Areas which are affected by lahar hujan from Bromo will be more fertile after some period if they are not dominated by sand materials".)

Landslides were a further hazard that frequently occurred in Mt. Bromo's surrounding areas. The type of deposited material, slope steepness and heavy rainfall were the triggering factors for the occurrence of landslides. In some places, landslides had a severe impact particularly with regards to road accessibility. However in other areas landslides contributed to the soil quality by transferring fertile materials.

The Bromo eruptions in 2010 were also characterized by Sulphur dioxide (SO_2) emissions. People who live within an area of 5–7 km radius from the crater cloud smell this gas emission. Their effect on plantations was described by *Bapak* Jarwo (40), Head of Ngadas village (5 km from Bromo crater):

"Di erupsi Bromo tahun 2010 desa saya hanya terkena dampak belerang, walau hanya satu hari saja kami merasakan bau itu, banyak tanaman mati khususnya kentang" (transl.: "At the Bromo's eruption in 2010 my village was only affected by sulphur dioxide emissions and although we could feel them only for one day, many plantations died, particularly potatoes").

The four major hazards (gas emission, tephra falls/ballistic, landslides and volcanic mud flow) produced by Mt. Bromo's eruptions had affected the human system in general and human settlement, human health, daily life activities, tourism activity, trading and transportation system as well as agricultural properties in particular. The volcanic

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eruptions mostly had negative effect for a short period during and after the eruption. However after the end of the eruption period, the community perceived and evaluated predominantly those effects that represented an opportunity. Agriculture, as the main livelihood of Tengger communities offered favorable conditions as soon as 1–3 years after the end of the eruptions. While during the eruption period, farmers became unemployed and lost their land and crops due to being covered by ashes they were able to capitalize on increased soil fertility after 1–3 years after the eruptions and were able to recover their losses.

4.2 Social context

The findings discussed above pertain to the environmental impact of eruptions. However, interviews with a number of informants and discussion in the FGD session show that the communities within the area interpret Mt. Bromo's eruptions not so much in specific terms of its environmental impacts but rather in its overarching cosmological meaning. Most people believe that Mt. Bromo always provides them with benefits for the continuity of their lives. The "Tengger community" whose earliest settlements can be traced back to the 16th century (Hefner, 1990) has strong faith in the benevolence of the volcano and interpreted its eruptions as a gift from God (see Fig. 6).

Hefner (1990) describes Mt. Bromo as the center of the Tengger cosmology. This notion can be confirmed based on the interviews we conducted. For example, at the interview session, *Bapak* Rudi, (50), Ngadirejo village official, said:

"Saya tidak pernah takut akan letusan bromo karena saya selalu percaya bahwa ini adalah letusan yang bersifat sementara, dimana letusan itu selalu memberi berkah terhadap kami semua. Kami percaya bahwa Bromo selalu memberikan apa yang kami perlukan disini" (transl.: "I am never scared of Bromo's eruption because I always believe that this is just temporary. Bromo's eruptions always benefit us. We believe that Bromo always gives us what we need to live here").

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The fact that "only [sic] two careless foreigners" died in 2004 was seen as a confirmation of *Bapak* Rudi's views. There is a firm believe in Mt. Bromo's benevolence and that in return there must be a positive attitude towards the mountain.

Local people do believe that Mt. Bromo will reflect the very attitude people have towards it: "Jika kamu berbuat buruk terhadap Bromo ataupun hanya berpikiran negatif, maka Bromo akan memberikan situasi yang sama seperti yang kamu pikirkan" (transl.: "If you do bad things or even just think negatively about Bromo, Bromo will provide a negative situation"), says *Bapak* Gunawan (55), Ngadas village official. Supporting this view, *Bapak* Ari, (50), Dukun at Ngadisari village, adds that: "Kita harus selalu berdoa yang terbaik untuk Bromo dan kehidupan disekitarnya" (transl.:"We should always pray for the goodness of Bromo and its life surrouding").

An interview with *Bapak* Wahyu at the FGD session in Ngadirejo, notably the head of *Kampung Siaga Bencana* (KSB is a community-based disaster program supported by the Ministry of Social Affairs) provides a local view, and thereby an understanding of the deep spiritual human-volcano relationship, on why the impact of the eruptions in 2010 was unusually severe for some villages within the Bromo area. He laments that the Tengger people did not do what their ancestors had told them. Before the eruptions, there agricultural yields were abundant, but most people, particularly the younger population used their income to buy motorcycles and consumer gadgets even if not really needed. Traditional saving systems were ignored and abandoned. Consequentially a number of villages lacked the resources to sustain the period of eruptions. Incidentally these villages were particularly affected by the eruption. *Bapak* Wahyu explains that if ancestral laws are not observed Mt. Bromo will punish society accordingly. This perception was also confirmed by other participants of the focus group discussion. It is a personified, directed threat of negative impacts that motivates disaster preparedness. The perception of the volcano as an animated being that interacts with and reacts to human behavior underlies local adaptation strategies.

Apart from belief-systems that link the local community with the volcano there is also intricate local knowledge of the physical environment that facilitates the interpretation

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of early warning signs of an imminent eruption. The interviews conducted revealed a number of such early warnings. For example an eruption may be imminent when excessive white smoke can be observed from the crater or when a stronger than usual odor of sulphur persists or when small volcanic tremors can be felt, particularly by people who live at or nearby the crater. Also, as one participant of a focus group discussion session, (*Mas* Joni (35)), farmer and young representative, Ngadirejo village, states: "Ketika tanaman jagung di tanah Mbako (lahan di lereng atas gunung tengger) mempunyai hasil yang bagus tetapi burung-burung menjauhi lereng tersebut, dapat dipastikan bromo akan meletus lagi" (transl.: "when the corn crop in "Mbako" land [sic: land at the upper slopes of the Tengger caldera] has good yields but birds stay away from the slopes, it can be sure that Bromo will erupt again".

The Tengger community assumes to be a part of the mountain. Land, water and forest of the mountain are the very source of their life, and thus the behavior of Bromo is intricately linked to their life.

This perceived and lived interdependence with Mt. Bromo is shared among all members of the Tengger community and leads to the establishment of social networks that go beyond the village. For example Ngadirejo, a village that was severely hit by the 2010 eruptions, received assistances from Ngadas village despite being also impacted itself. Ngadas villagers provided goods such as rice and vegetables from their own agricultural land. Assistance went as far as offering their agricultural land to people from Ngadirejo for cultivation. When asked about this, our informants answered that "We, the Tengger people, are reminded by this eruption that we are one community. We must help each other. This eruption makes the bond between us become stronger". Thus the eruption strengthened the social fabric among Tengger people. While a spirit of community and altruism can often be observed in the aftermath of disasters it seems that being reminded of a common spiritual link to the volcano was viewed and reflected as a positive, community building outcome and indeed underlying the communal bonds.

The Tenggerese also exhibited a remarkable adaptive capacity to the circumstances during the eruption period. *Ibu* Rita, farmer (34) from Ngadirejo village explained that

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the eruptions generated considerable touristic interest toward the end of the eruption period and says: “Kami sementara waktu berpindah pekerjaan dari bertani ke sektor wisata, karena pada saat itu tidak memungkinkan untuk kami mengolah tanah pertanian kamu karena abu vulkanik. Pada akhirnya ini sangat bermanfaat bagi kami” (transl.: “we temporarily shifted our livelihoods from cultivating land to the tourism sector, because at that time we could not cultivate our agricultural land due to volcanic ash materials. At the end this was very favorable for us”).

5 Discussion

In the cited literature below the question of how culture enables people to live with volcanic hazard has been asked and cultural adaptations as explanations have been put forward in many cases. We want to go beyond the question of *how* people live with, at least periodically adverse conditions in their natural environment. Therefore we reframe observations made in a range of investigations on cultural adaptation to volcanic hazard as contribution to answering the question that guides our analysis here, which is: *why* do people choose to live exposed to largely unpredictable hazard? In the remainder of this chapter we argue that what has been identified as cultural adaptations to hazard can be viewed as a good in itself that in order to obtain the exposure to hazard is vital.

5.1 Socio-cultural benefits of volcanic risk

Wherever they are in the vicinity of volcanoes societies have fundamentally been shaped by recurrent eruptions. Belief-systems and agricultural practice, mythology and social structure, traditions and politics are shaped, and more often than not, centered on the existence of potential volcanic hazard. A diverse body of literature shows that this holds true for societies that no longer exist (Cashman and Giordano, 2008; Plunket and Uruñuela, 2008) as well as it can be observed today the world over (Cashman and

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Cronin, 2008; Paradise, 2005; Gregg et al., 2008; Siswowidjoyo et al., 1997). Various disciplines analyze the multi-layered relationship that exists between human societies and volcanic risk. Anthropological research looks at the way that volcanism is embedded in mythology through the prism of geomythology. Natural events and human life – meaning the state of society – are always seen as being interconnected (Oliver-Smith, 1996; Schlehe, 2010, 1996). People 'domesticate' the volcanic threat (Dove, 2008) and are surprisingly not scared (Lavigne et al., 2008) to live in its vicinity. Dove (2010) analyses the role of Mount Merapi in Java in the context of public opinion, power relations and political decision-making in Java from a philosophical and historical-political perspective. Other scholars, such as Donovan (2010) explore social volcanology, particularly culture at Merapi volcano. Results show that a mixture of factors influence people to stay in the vicinity of Merapi volcano. These include cultural beliefs, such as safety provided by spiritual powers, the abundance of livestock and positive past experiences. In addition, religious studies observe how the threat and fallout of volcanic hazard is interpreted and aligned with the divine. Here the principle of understanding natural hazard as punishment for sinful conduct is captured in the concept of theodicy (Wisner, 2010; Chester, 2005; Chester et al., 2008). For example victims of volcanic hazards are seen as martyrs following Islamic interpretations of natural hazards. Chester et al. (2013) point out that this interpretation must not to be seen as complacent fatalism but rather as human humbleness. Recurrent eruptions fit well with cosmologies that understand destructive physical processes as new beginnings and part of the cyclical nature of all things (Heine-Geldern, 1956; Schweizer, 1991; Chester, 2005). The cycle of destruction and creation that is so immediately manifest in recurrent volcanic eruptions resonates also in Christian religious adages if one thinks of the phrase from the Anglican burial service "ashes to ashes and dust to dust".

Contrary to the view that habitation in volcanic hazard zones is mostly a result of marginalization and economic pressure (Wisner et al., 2004; Lavigne et al., 2008), the results of our field work confirm what the cited literature implicitly suggests, that people choose to live with volcanic hazards because they are not only exposed to

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negative consequence but also reap the benefits and opportunities that arise within a human-volcano system. Within a human-volcanic system perspective the focus must be widened and include social and physical processes that pertain to the entire system and go beyond eruptions and their immediate and detrimental consequences.

Volcanoes are a powerful force in shaping cultural identity. Rather than an environmental hazard to avoid at all costs, people's cultural identity is centrally inspired by "their volcano". The very essence of who the Tenggerese are revolves around the volcano and without it they would culturally seize to exist. By inspiring cultural identity the human-volcano system produces socio-cultural benefits in direct and indirect form. These benefits emerge only to a lesser degree directly from eruptions. However, the pivotal and multidimensional role of the volcano within the system produces a range of system strengthening and capacity building outcomes. These revolve around social structure and position therein, as well as grounding through heritage and ancestral lineage. People gain their very place on earth through the existence of the volcano (Schlehe, 1996).

In this sense it was at no surprise that in our analysis of semi-structured interviews and focus group discussion we found an overwhelmingly positive attitude toward the Mt. Bromo eruptions. The positive aspects that are our focus here were developed during and after conducting the interviews when it became apparent how positive people's attitude towards Mt. Bromo really is. What follows is a list of cultural adaptations reframed as socio-cultural benefits that in order to obtain, people may weigh against the cost of potential hazard. In no particular order we propose the following five items as socio-cultural benefits stemming from cultural identity of living within a human-volcano system.

- Resilience and capacity to recover
  Directly linked to cultural identity is the specific capacity of individuals and communities to recover from disaster. In the aftermath of a natural disaster a community's capacity to recover psychologically and spiritually is equally important as the ability to recoup in a physical and economic sense (Chester, 2005). By

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occupying an important place in people's cosmology rather than being perceived as a mere fluke of nature, a hazardous volcano itself is at the basis for psychological and spiritual recovery. For example Schlehe (1996) observes a 'sense of security through the spirit world' that is governed by the volcano, and further that supernatural metaphors, story-telling and culturally accepted forms of explaining loss all contribute to resilience. Thereby the volcano itself becomes the source of people's capacity to recover – it is curse and blessing simultaneously.

– Attachment to place and hazard knowledge
Owing to their distinctness and the relatively small spatial extents of human-volcano systems the volcano instils a local attachment to environment and place. This may lead to a heightened sense of stewardship and sustainable environmental resource management. The particular demands of the hazardous environment and resulting engagement with the volcanic system lead in turn to local knowledge and hazard management strategies.

– Social and moral order
The interpretation of loss, destruction and suffering from volcanic hazard as a punishment for sinful conduct sent from the divine not only reconciles and justifies in the sense of theodicy but helps to uphold social and moral order. For example are such interpretation and the threat of disaster used to reinforce the prohibition of alcohol and prostitution (Chester et al., 2013; Schlehe, 1996).

– Means to frame and voice dissent
The freedom to interpret natural events as a direct reflection of ills in society as for example unjust power relations, land ownership and corruption enables people to frame and voice dissent safely and embedded in a larger cosmological setting. Oliver-Smith (1996) notes that "disasters create contexts in which power relations and arrangements can be more clearly perceived and confronted, which transforms political consciousness, shapes individual actions, and strengthens or dissolves institutional power arrangements".

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– Catalyst for change processes

Volcanic eruptions have been described as “agents of change” (Dove, 2008; KV Cashman and Giordano, 2008) in a physical as well as socio-political dimension. The perturbations of volcanic eruptions have brought about changes ranging from the economic basis of local livelihoods and settlement patterns to social organization and power relations. As noted by Dove (2008) these changes have often been for the good and are integral part of the human-volcano system.

We argue that these socio-cultural benefits are, even where in no direct physical relation nevertheless a consequential outcome of living with volcanic risk. They inform and contribute to the active choice to live exposed to volcanic hazards. Further, they can only be understood in a wider human-volcano system perspective that goes beyond geophysical analysis and traditional risk concepts in natural hazard research.

5.2 Risk and open risk concept

Traditionally scientific examinations of natural hazard processes were conducted from a pure natural scientific and engineering point of view not including societal aspects. The only way society was addressed if at all was in the role of a potential victim which had to be protected from losses. Although the principal idea of risk rooted in Medieval Mediterranean maritime trade is related to both potential profit and loss, this open understanding of risk does no longer feature in modern risk analysis (Banse, 1950; Fuchs et al., 2004). In lieu thereof, since the 1950, risk concepts were developed in different disciplines in various contexts (Dikau and Weichselgartner, 2005; Müller-Mahn, 2007; Renn et al., 2007). Focusing on flash floods, their perception and assessment, Kates (1962) and White (1964) introduced risk aspects into natural hazard research. Based on this approach, which integrated aspects of physical geography, social sciences and economics, a first comprehensive natural hazard risk analysis may be attributed to Petak and Atkinsson (1982). In recent years, process-oriented concepts have been replaced

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by a more sophisticated integrative risk management (e.g. Ammann, 2001; Stötter et al., 2002) or ideas towards a so called risk society (e.g. Beck, 1992, 2009), risk culture or risk governance framework (e.g. International Risk Governance Council, 2005). However, similar to other natural hazard risks, volcanic risks remain to be connoted with negative impacts on society. But as shown in this paper, all these (traditional) risk perspectives cannot explain the perception and decision making in the Bromo human-volcano-system. Gaillard (Gaillard, 2008) found in his research at Mt. Pinatubo that high perception of risk does not discourage people from living in hazard prone areas. Lack of opportunity development to create alternative livelihoods is a strong incentive to live with volcanic hazard. In this sense, only an open risk concept (see e.g. Campbell and Vuolteenaho, 2004; Stötter and Coy, 2008) which allows including both potential positive and negative outcomes can help to explain the attitude of the local population in the Mt. Bromo region. On a theoretical level, in such open risk concept, all future developments intrinsically exhibit some degree of uncertainty bearing options for both good risk, i.e. an opportunity to be grasped, and bad risk in the classical sense of a negative outcome to be avoided. In a human-environment system, the linkage between impact and the exposed systems is generally determined by the sensitivity of the reacting system to the external impulse. That means that vulnerability and capacity, respective resilience are the interacting factors that govern the dimension of risk and as a consequence the adaptability of the human-environment system whatever consequences, negative or positive, may occur. In the Bromo human-volcano-system, the local population perceives volcanic activity as source of both, the threatening destructive forces as well as the agricultural basis of existence and spiritual home of their community. Based on their cultural system of values, in their interpretation, the good risks provided by Bromo volcano do more than compensate the bad risks and thus they accept their living conditions in the Mt. Bromo area. The risk perception of the Tenggerese and their consequential behavior is very similar to the understanding of Medieval merchants who first created the term *"risco"*: the Tenggerese understand the gain of accepting risk with all its consequences. We suggest that a holistic understanding of risk, be it

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a forgotten medieval concept or alive in local knowledge, must inspire the way in in which we address an open and uncertain future in times of global change processes. While modern, engineering-based risk research has provided us with practical tools of risk assessment, evaluation and monitoring, it is now time to reintroduce what is on the upside of the coin – the opportunities that humans sought whenever they chose to expose themselves to risks.

6 Conclusions

The empirical research discussed in this paper shows that the interaction between human and volcanic environment at Bromo volcano is multifaceted and complex. The Tengger people of the Bromo area choose deliberately to live with volcanic hazards. They do so because they do not feel only exposed to negative consequences of volcanic hazards, but also enjoy benefits and opportunities of physical, spiritual and sociocultural nature that arise within the human-volcano system. We confirm five cultural adaptations as actual benefits originating from cultural life within Bromo human-volcano system. These are heightened resilience and capacity to recover; attachment to place and hazard knowledge; source of social and moral order; means to frame and voice dissent; catalyst for change processes.

Following this perception, the concept of risk itself must be revisited and expanded from a one-sided focus on hazardous processes to a more holistic view of risk that includes the various positive aspects that pertain to the entire system. It is cannot be fully understood within a simple exposure/vulnerability risk concept. The development of a generic human-volcanic system model could provide the basis for the development of an open risk concept.

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Table 1. Chronology of Bromo eruption in 2010 (CVGHM, 2010).

Date	Time (UTC+7)	Activities	Alert level
8 Nov	14:00	The volcanic ash color significantly changes from white to grey color. After one hour, the number of volcanic tremor had increases.	II (WASPADA)
20 Nov	05:00	Explosive eruption begins with the source from Bromo crater. The height of volcanic plume reaches 200–250 m in the sky. The duration of the explosion lasts 30 min.	III (SIAGA)
23 Nov	05:00 14:00– 16:30	Recurrent explosions, with the height of the volcanic plume reaching 400 m. At 2 p.m., the explosion becomes more violent and the volcanic plume reaches 400–800 m. The Bromo volcanic status changes from SIAGA/level III/Be Ready to AWAS/level IV/Danger. The maximum amplitude increase significantly from 5 mm into 30 mm in 7.5 h.	IV (AWAS)
25–29 Nov		Bromo still erupts with the volcanic plume reaching 400–800 and exudes brown volcanic ash.	
6 Dec	12:45	The volcanic status changes to the lower status from "Danger" to "Be ready as the volcanic activity slows down".	III (SIAGA)
13 Dec		Continuous eruptions occur with tremors of 5–15 mm.	
19 Dec		The explosion increases with the record time at 10:17 and 11:27. This condition continues for a sustained period of nine month of eruptions.	III (SIAGA)
Jul 2011		Mt. Bromo's eruptions come to a halt*	

Note: WASPADA = "Be careful", SIAGA = "Be ready", AWAS = "Danger", * Data from field survey.

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Table 2. Survey method at village around Bromo volcano.

	Probolinggo District	Malang District	Pasuruan District	Lumajang District
Village	Ngadisari, Sumber, Wriningan om, *Ngadirejo	Ngadas	Wonokitri, Tosari	Ranupane
Justification of surveyed village	– Closed to the crater (CVGHM, 2010) – Habitant by Tengger community (Indigenous Bromo community) (BPS, 2011) – Categorized as effected village by Bromo eruption (BPBD, 2011)			
Technical survey approach	Secondary data collection, semi-structured interview. * Focus Group Discussion	Secondary data collection, semi-structured interview	Secondary data collection, semi-structured interview	Secondary data collection, semi-structured interview
Date of survey (month yr^{-1})	Feb–Mar 2012 Jul–Sep 2012 *Feb–Mar 2013	Feb–Mar 2012 Jul–Sep 2012	Feb–Mar 2012 Jul–Sep 2012	Feb–Mar 2012 Jul–Sep 2012
Interviewed people and their function (Note: the names of informants are changed to protect their identity)	– Ngadisari: *Bapak* Ari (Dukun) – Ngadirejo: *Bapak* Yudi (Head of village), *Bapak* Wahyu (Head of KSB), *Bapak* Rudi (Farmer and village official). *Ibu* Rita (Farmer) – Sumber: *Bapak* Budi (Farmer) – Wriningan om: *Bapak* Kirno (Head of village),	Ngadas: *Bapak* Jarwo (Head of village), *Bapak* Gunawan (famer and village official)	– Wonokitri: *Ibu* Ambar (Head of village), *Bapak* Sutrisno (Dukun), *Ibu* Yanti (Teacher), – Tosari: *Ibu* Erna (Official government of agriculture department)	Ranupane: *Bapak* Supardi (Farmer)
Focus Group Discussion participants (Note: the names of informants are changed to protect their identity)	*Bapak* Wahyu (Head of KSB); *Bapak* Yudi (Head of village,); *Mas* Joni (Young representative, farmer); *Bapak* Harjono (Head of hamlet 1, farmer); *Bapak* Tukiman (Head of hamlet 2, farmer); *Bapak* Sukur (Head of hamlet 3, farmer); *Bapak* Imam (Farmer); *Bapak* Sunarko (Farmer)			

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Table 3. Questions asked during semi-structured interviews and focus group discussion.

Question	Rationale
Question about: Personal details (name. age, education background, gender, religion, occupation, members of family)	Socio-Demographic
Have you always lived in this village? If yes could you tell me about Bromo and the surrounding area?	Local environmental knowledge
What is the meaning of Bromo in your life?	Life value, risk and benefits
What is your ancestral story about Bromo?	Culture and folklore
What is your experience of Bromo eruptions?	Memory, hazard knowledge
What kind of hazards are you aware of? And how is your area affected by them?	Hazard knowledge
Please tell me about Bromo's hazard zones? Is your village categorized as hazard prone area? And how about other villages?	Hazard and local environmental knowledge
Think about the last eruption, how dangerous was this eruption for you? Do you dread Bromo? Please share your feelings.	Risk perception
In your opinion, do you think that Bromo will erupt again in the near future? Why? Could you tell me signs for imminent eruption?	Risk perception, Hazard knowledge

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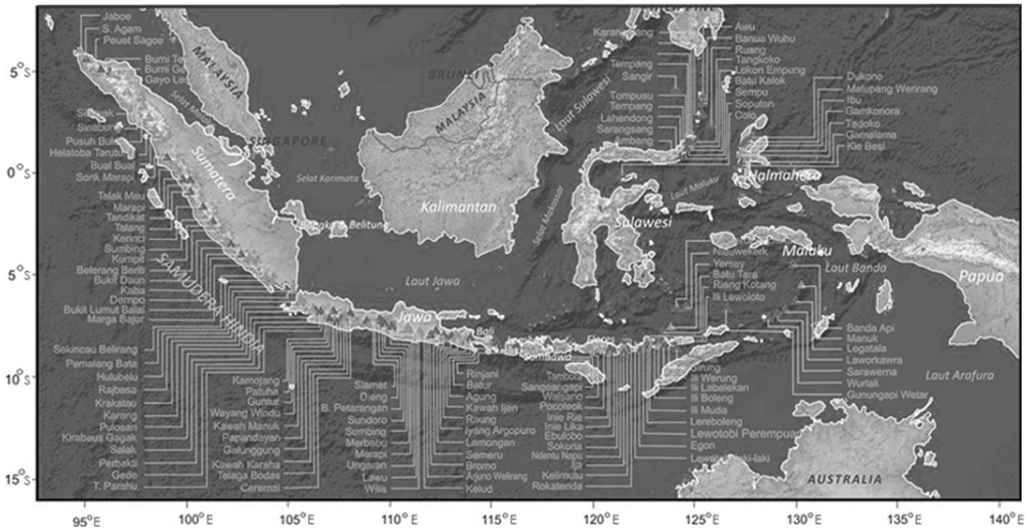

Figure 1. Distribution of active volcanoes in Indonesia (Surono, 2013).

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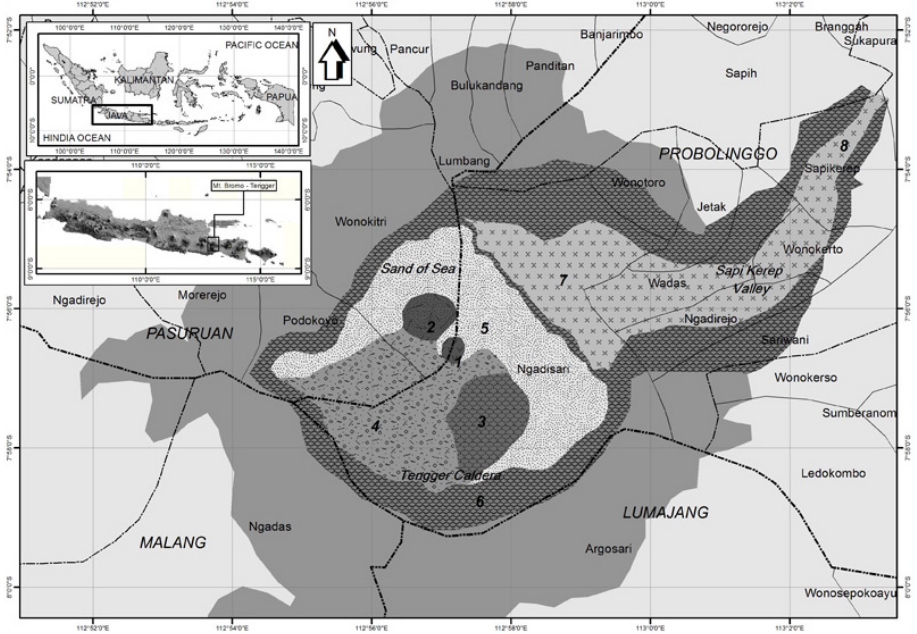

Figure 2. Bromo volcano and its landforms (1) Gunung Bromo and its crater; (2) a strombolian cone, Gunung Batok; (3) complex of rest volcanic cone (G. Widodaren, G. Kursi); (4) Sand of Sea (Segarawedi Kidul and Segorowedi Lor); (5) Tengger caldera formation (upper and middle slope); (6) Foot slope of Tengger caldera (Sukapura Baranco); (7) Sapi kerep outlet valley. (Interpretation from SRTM Image and field survey).

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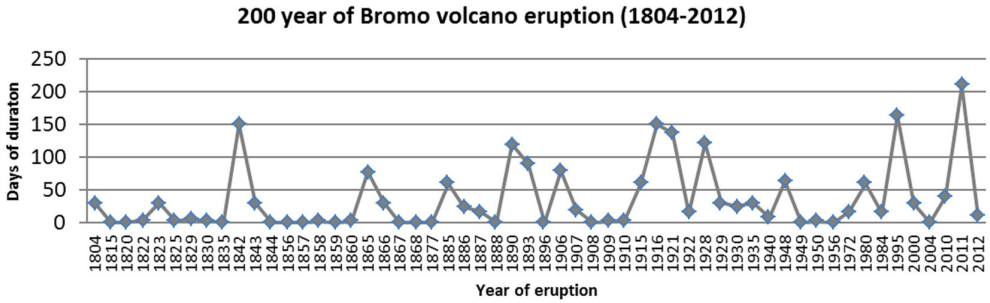

Figure 3. Year and duration (days) of Mt. Bromo eruption in 200 years period (For 1804–2010, CVGHM 2010 and for 2011–2012, Field survey, 2012).

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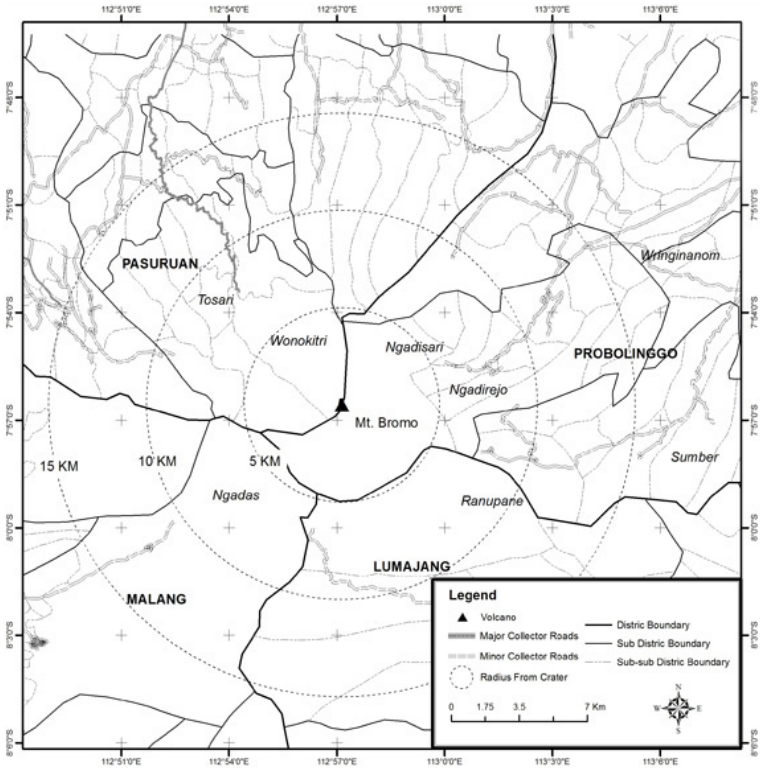

Figure 4. Map of surveyed village in Bromo volcano area.

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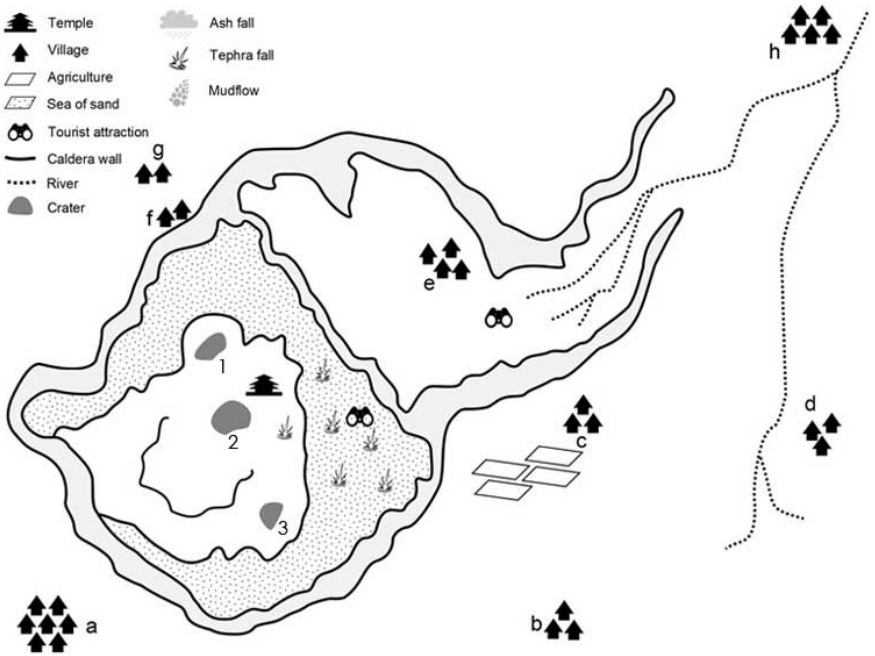

Figure 5. Human-volcano system in Bromo volcano. (1) Mt. Batok, (2) Bromo volcano, (3) Mt. Kursi, (a) Ngadas Village, (b) Ranupane Village, (c) Ngadirejo Village, (d) Sumber Village, (e) Ngadisari Village, (f) Wonokitri Village, (g) Tosari Village, (h) Wriningan om Village.

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Figure 6. Religious ceremony at Puten temple inside the Tengger Caldera during the eruptions (Triono, 2010).

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