The biodiversity of Krem Mawkhyrdop of Meghalaya, India, on the verge of extinction

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Cave fauna are unique and constitute one of the important components of biodiversity. The prevalence of cave organisms (cavernicoles) is always more in wet and longer caves compared to small and dry ones. Cavernicoles continue to evolve in the habitat characterized by complete darkness, constant temperature, high humidity and low predatic pressure. The subterranean biospheres located in tropical and sub-tropical India are poorly explored. Quarrying/mining activities in the karst area directly or indirectly harm such subterranean biosphere. Krem Mawkhyrdop located in Meghalaya, is affected by such activities. Recently, a portion of this cave collapsed despite early warning calls. In this article, we explain how an unscientific and random quarrying/mining process may possibly lead to extinction of biodiversity of this cave.

Keywords: Cavernicoles, cave collapse, subterranean ecosystem, quarrying/mining process.

THE adjoining geophysical architecture and climatic conditions always act as proximate factors that regulate the internal environmental conditions of any cave. Nevertheless, the cave (hypogean) ecosystem remains more or less stable compared to its ambient epigean environmental niche. Perpetual darkness, high humidity, almost constant temperature, low airflow and higher CO_2 concentrations altogether make the subterranean ecosystem a unique niche. The biota of the caves stays tuned with its ecological regime for successful survival. The biodiversity of the karst ecosystem is highly restrictive, i.e. species existing in a particular cave system may be restricted to that ecosystem only and perhaps completely absent in other adjacent caves. Any natural/unnatural disturbances that can alter/modify the originality of the cave ecosystem could become a major deciding factor to destroy/alter its complete biodiversity. Natural geological disasters (i.e. collapse, wall dislocations, etc.), climatic abnormalities (long period of droughts, inundations) and mostly human encroachments (mining/quarrying, tourism, waste disposal, and rapid ways of agriculture) are some of the factors that are responsible for the same.

Krem (=cave) Mawkhyrdop is situated in the village Mawmluh, Meghalaya (25.30°N, 91.70°E), India. It is popularly known as the Mawmluh cave. This area enjoys the highest rainfall in the world. In fact, the monsoon sweeping the Bay of Bengal results in an average of 10–12 m rainfall per year. The combination of huge limestone deposits of this area with high rainfall has led to extensive cave development in Meghalaya. The Mawkhyrdop cave was for the first time lighted in the 18th century along with a small cave Mawsmai in the same region, at a distance of about 10 km. In 1859, Oldham[1] reported the existence of these caves. The Mawkhyrdop cave is formed of pure limestone (Cherra limestone) with both sides covered by sandstone beds (with some coal at the bottom). Thus the sandstone at the base of the Mawkhyrdop cave is a limiting factor for its vertical development. Frequently calcirudite, a coarse (gravel-sized) limestone can be viewed on the walls. These clasts (broken fragments) are suspected to be rock fossils or pieces of coral, shells or fragments of limestone, with the interstices filled with calcite, sand or mud with the whole bonded by calcareous cement. The cross-section of the cave passages resembles the shape of an inverted funnel. This feature is quite peculiar with Krem Mawkhyrdop (and a couple of other caves in Meghalaya), as it is a typical product of inter-stratal karst[2], developed in a layer sandwiched between sandstones limiting vertical development[1]. The rate of seepage was noticed to be high inside the Mawkhyrdop cave compared to the other tropical caves.

Before analysing the present condition of this cave, one must be aware of its geographical situation along with the socio-economical conditions of that part of the country. The cave belongs to the northeastern part of India. The region was once well known for its rich greenery belt as well as tribal people. In addition, this part of India is highly rich in natural resources, oil, natural gas and minerals. Extensive deposits of limestone, nearly 350 m thick, occur in the small state of Megalaya. However, the core zone of this cave area possesses only 27 m of limestone, which is unable to support proper agriculture. In this zone, both the karstified limestone

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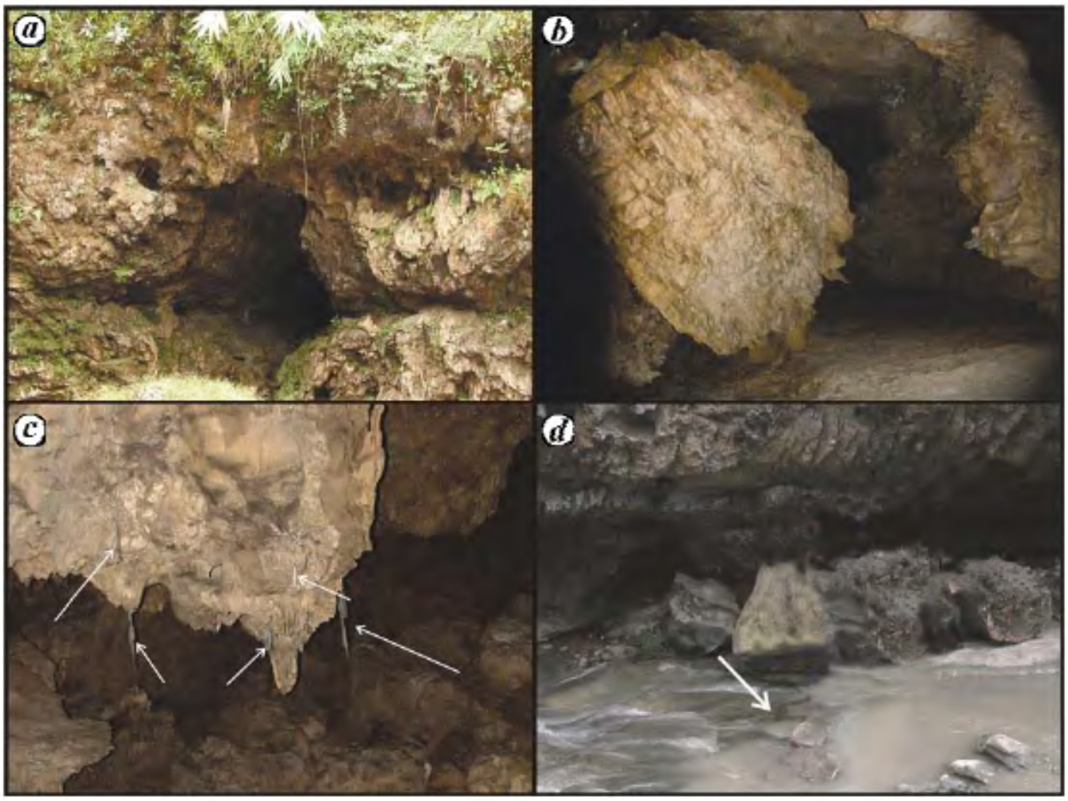

Figure 1. *a*, Main entrance of the cave. *b*, Huge dislocated block lying inside the cave. *c*, Arrows representing clothes and polythene pieces hanging inside the wall of the cave. *d*, Arrow representing the point where chemical effluents mix with clear river water before entering the cave.

outcrops as well as the underlying sandstone fail to retain sufficient moisture. Thus except during the rainy season, the greenery belt is almost absent in the flattened area of this zone. Besides this, the socio-economic status of the local tribes is not sound. To strengthen the same, several lucrative schemes were launched by the Indian Government to establish mining-related industries in this area. Unfortunately, due to lack of adequate information about the existing subterranean caves, no proper guidelines were given for its protection. Therefore, the present scenario is worsening day by day.

Present status of the cave

The Mawkhyrdop cave is situated at end of the river. It could be better to state the spot as sinking river, perhaps, which was once in 1844 reported by Henry Yule[3]. This cave is one of the longest in the Indian sub-continent. Brooks and Brown[4] surveyed its length of about 7194 m. The main cave entrance or insurgence is about 2 m above the ground level (Figure 1 *a*). In addition, an alternate visitor's entrance lies adjacent to it and consists of a relict cave some 2–4 m vertically above the riverbed. To enter through the main entrance one has to wade through water. During the dry period one can easily feel the cemented layer at the bottom and also the smell of petrochemical products. However, a dry, narrow passage also runs parallel to it, but it may be inconvenient for the tourists or non-cavers. The main passage leads to a big chamber of about 25 m diameter. Several narrow water streams ensuing from the bottom level of the cave entrance take the shape of a big river stream about 10–12 m wide, inside the cave. Interestingly, this cave has a five-river passage with almost equivalent proportions: (a) Main stream or 'MS', from where the cement works effluent enters, is about 150 m^2; (b) The Dogskull stream (or 0.060 MS) about 20 m^2; (c) Allsup inlet (0.013 MS) about 4.5 m^2; (d) Slurry slump (0.060 MS) of about 20 m^2; (e) Candle inlet about 1.5 m^2, and (f) White path inlet (0.011 MS) about 4 m^2. Occasionally few unknown inlets also seem to develop and simultaneously disappear (Figure 2).

Cave organisms (cavernicoles) negotiate the most common geophysical characteristics of the subterranean caves, such as sporadic food supply, low predatic pressure and life in continual stress. Therefore, various physiological adaptations with several behavioural and morphological divergences could be noticed in such cavernicoles, that often places them in a separate taxonomical status. However, the cavernicoles have been broadly categorized into three groups based on their affinity towards the cave-adapted life. (1) Trogloxene – species

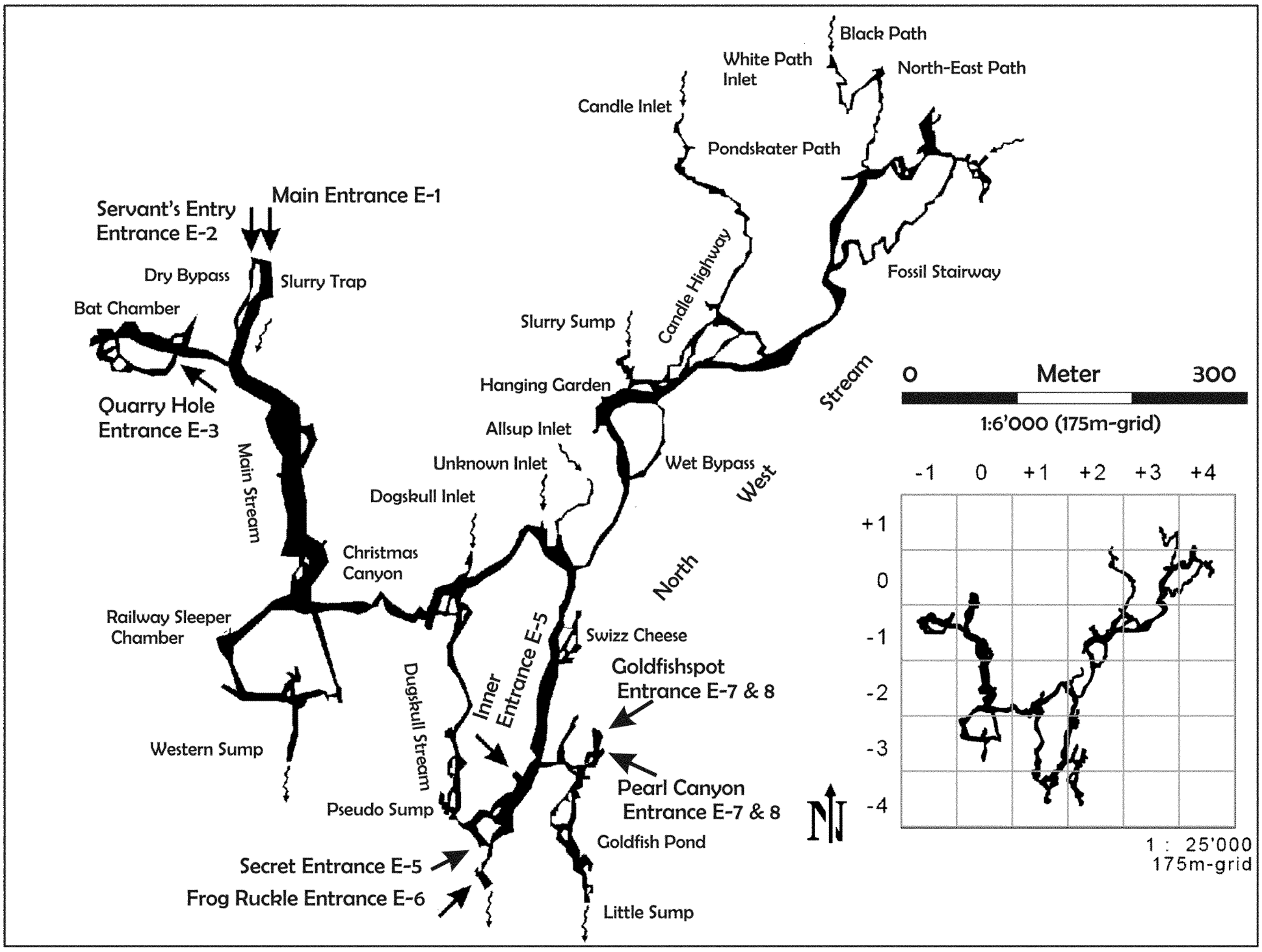

Figure 2. Tentative layout of the Mawkhyrdop cave, showing all the inlets, paths and approximate length.

which visit or take shelter but do not complete their whole life cycle in the caves. They go to the outer world periodically for some requirements, usually food (e.g. bats, frogs, lizards, crickets, etc.). Further, this group can be divided into accidental trogloxene and habitual trogloxene. (2) Troglophile – species which live permanently in the dark zone, some of which can also survive in a suitable habitat away from the cave. This could be referred to as future troglobites (e.g. fish, salamandar, crayfish, millipedes, etc.). (3) Troglobite – species which live wholly and permanently in the dark zone of the caves. They are mostly blind, albinic, with extra sensory organs developed[5] (e.g. same as for troglophile). The Mawkhyrdop cave serves as an abode for all three categories of cavernicoles.

Surroundings

Hypogean biodiversity could be understood properly after understanding the regional epigean patterns of the concerned cave. Usually due to bleak water-holding capacity the floral occurrence is low in the Karst area. Notwithstanding this, random deforestation gives the complete surrounding a barren look. To make it simpler, one has to try hard to fetch even a spike of grass in some specific landscapes of this area.

Frequent earthquakes are a general phenomenon of this area. This is responsible for the sudden breakdown of the stalactite/stalagmite column and or wall/ceiling of the cave. A huge dislocated block lying inside this cave could be the result of such a phenomenon which appeared with a high threshold during 1955 (Figure 1 *b*).

At about 200 m from the main entrance of the cave, a cement factory has been functioning since 1961, being involved with captive limestone quarrying. Irregular blasting pattern and unscientific ways of discharging factory effluent can be easily noticed here, which directly enters to the cave system along with the river stream (Figure 1 *d*). Though the Karst system has low self-purification capabilities[6], contaminated water enters the cave through various conduits (coming under the mining block). This is not only dangerous for the cave biota, but is also responsible for the collapse of important conduits of the same zone. During mining, leakage from machines (hydrocarbons), other chemicals and even explosives are some of the major and potential sources of contamination.

Besides, domestic sewage is also polluting the cave aquatic system. Regular discharge of organic/inorganic domestic sewage from the adjacent human colonies enters this cave. High flooding during the monsoon provides clinching evidence of cloth and polythene clinging to sidewalls and ceiling of the cave (Figure 1 *c*). Non-degradable items like polythene pieces not only contaminate the cave environment, but also block several conduits and the major streams.

Biotic factors of Mawkhyrdop cave

The cavernicoles occupy a particular niche in the cave, based on their degree of evolution, to lead a successful subterranean lifestyle. The subterranean environment has been divided into four different zones[6] depending upon the characteristics of constancy of their immediate geophysical parameters: (1) The twilight zone, near the entrance, where light intensity, humidity and temperature vary. This zone is occupied by a variety of fauna specially belonging to both the habitual as well as accidental trogloxene categories. (2) The transition zone of almost complete darkness with variable humidity and temperature. This zone has been found to be occupied permanently by several kinds of species, which can even survive in the external world. Habitual trogloxenes along with a few varieties of troglophiles prefer this zone. (3) The deep zone of complete darkness with almost 100% humidity and constant temperature. This zone seems to be occupied by absolutely cave-adapted species, which given a chance may fail to cope with the epigean environmental conditions. This zone may be referred to as absolutely belonging to the troglobites. (4) The stagnant zone of complete darkness with 100% humidity and where there is little air exchange, and CO_2 concentration may become high. The zone is not preferable for any life form or a high degree of adaptation is needed to survive in this zone. However, from time to time several micro fauna such as amphipods and/or copepods have been reported from this zone[7,8]. During our survey, we focused on macro faunas of the cave. We trapped all available fauna from their original habitat, noted their major taxonomical characters and photographed them for identification at least up to the genus level. Available database[5] was used to identify the species.

We succeeded in documenting only a few fauna, although this is one of the biggest caves in the world.

Terrestrial fauna

Besides a few thrips and small flies, the wall and ceiling of this cave was found to be mostly occupied by crickets (Figure 3 *a*). The faint body coloration and large-sized antenna testified it to the cavernicolous group, *Rhaphidophoridae* sp. The occurrence of several nymphs showed that it has been successfully continuing its phylogenetic race inside this cave.

During our survey, we noticed only a few colonies of a single microchiropteran bat, *Rhinolophus pasillus*, commonly known as horseshoe bats (Figure 3 *b*). However, a well-defined bat chamber also exists inside this cave, which is a roosting site for thousands of bats. Although the cave is also known to harbour snakes, we did not record any. However, the snake could be referred to as either accidental or habitual trogloxene.

Aquatic fauna

Apart from the continuous-flowing river stream, several water pockets could also be easily observed throughout the main tunnel of this cave. These water ditches perhaps become a part of the flowing river stream during high water pressure or flood. Our team failed to collect a single aquatic fauna from the main stream of this river cave. However, few invertebrates were noticed in the existing stagnant water ditches (Figure 3 *c* and *d*). Only the shrimp, *Macrobranchium* sp. could be considered as troglophilic, due to its light pigmentation characteristics, whereas further studies are required to designate the cavernicolous status of the observed crab.

Possible factors for depletion of biodiversity

The cave ecosystem always represents fragile characteristics; even a minute alteration may disturb the complete balance. However, the Mawkhyrdop cave is facing all sorts of disturbances, which are day by day degrading the complete biodiversity of the cave. To understand the factors possibly responsible for the biotic depletion, one has to understand the epigean ambient environmental conditions around the cave.

When an explosive is detonated in the mine, enormous amount of energy is released and most of it is used up to replace the rock from the site of the quarry work. In addition, some energy is wasted as sound, light/fire and others in some minor ways. However, it cannot be ignored that a part of the energy is transmitted through the rocks as shear wave, which is commonly negligible in normal cases. As far as the cave itself and its biota are concerned, such vibrations not only weaken the walls and ceiling of the cave, but also threaten the existing bats to search for an alternative roosting site. Noise and air concussion produced from the blast also disturb the colonies of bats. These disturbances can occur as far away as 1500 m from the quarry if the opening of the roosting cave happens to be facing the direction of the blast[6]. Further, the rapid deforestation in the ambient epigean ecosystem also

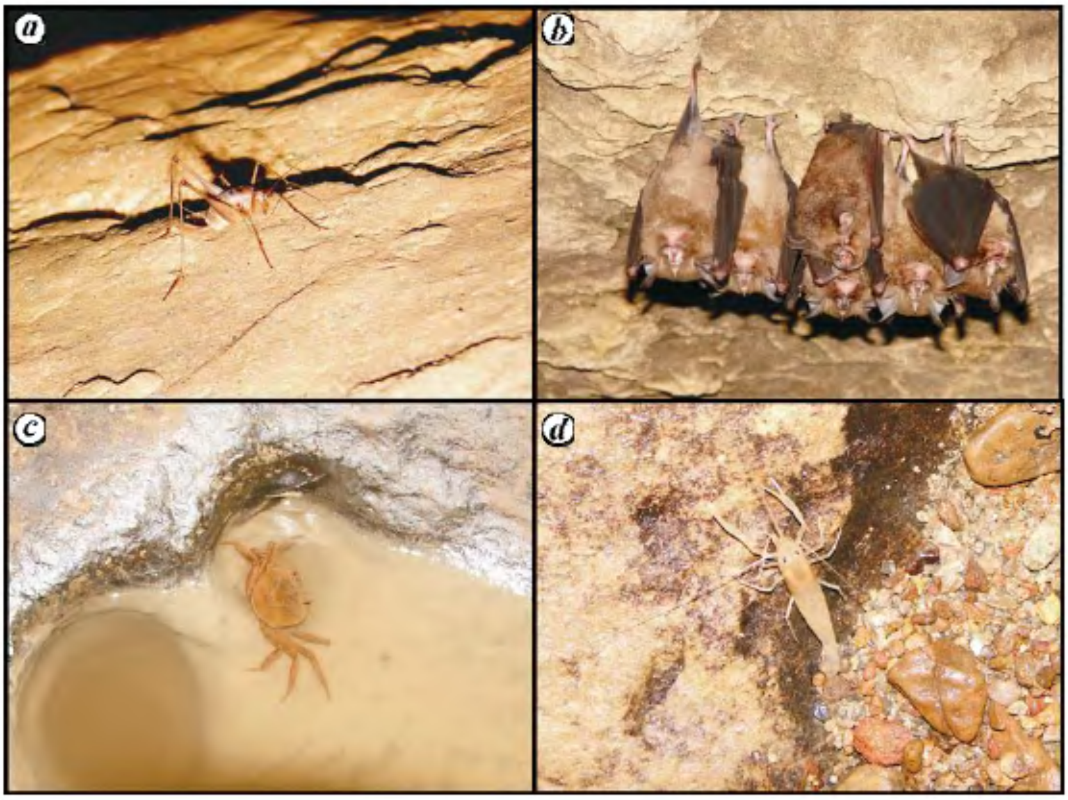

Figure 3. ***a***, *Rhaphidophoridae* sp., cave cricket with cavernicolous characteristics. ***b***, *Rhinolophus pasillus*, commonly known as horseshoe bats. ***c***, Crab, accidental or cave habitat? ***d***, *Macrobranchium* sp., stygophilic (troglophilic) shrimp.

depletes the food web of the cave bats and ultimately compels them to search for an alternative roosting site. Depletion of the bat population restricts the life cycles of various other cavernicoles, which may directly or indirectly depend on the cave bats for their food sources[7–9] and other physiological activities of their life system[10,11].

The cave entrance always regulates the existence of biotic and abiotic factors of its interior ecosystem, as the cave entrance is the only major input site of the potential food[7–10]. Influx may be in the form of dead organic matter (leaves, debris, etc.) or small living creatures directly via the water stream or airflow. Species diversity has always been reported manifold in the cave entrance, where hypogean and epigean fauna are mixed[12–15]. Nevertheless, the main entrance of the Mawkhyrdop cave is more or less the key point through which the cave gets polluted. The mining effluents with the river stream rush in continuously, which is neither fit for the survival of any aquatic fauna (particularly at the entrance zone), nor in retaining any nutritive value of the organic matter entering the cave with the stream. Therefore, it could be presumed that the cavernicoles belonging to the twilight zone of the caves are already under extinction.

Quarrying may intersect active groundwater conduits and even cause their blockage, resulting in adverse consequences, especially for the aquatic cavernicoles. Alterations of flow volumes/patterns with the availability of the nutrient can profoundly change the limestone environment and may lead to the extinction of the completely dependent community[6]. In addition, the harmful effluents reaching the cave via sub-conduits/seepage may destroy the microbial ecosystem normally found in these environments. As our understanding of these subterranean microbial processes increases, including the role that they play in speleothem development, pollution and/or altering groundwater flow not only ceases the complete speleothem process of the cave, but also detrimentally impacts the energy acquisition systems of organisms existing in the deepest zones of this cave[16].

Thus all the major energy influx channels of this cave are the sources of cave pollution, hazardous for its inhabitants. This has been depicted in a schematic diagram of the food pyramid operating in the Mawkhyrdop cave (Figure 4).

Conclusion

The subterranean ecosystem harbours rare and endangered fauna. Surprisingly, its relevant ecological processes are poorly understood; often these special niches are threatened by anthropogenic encroachments. The subterranean caves with subterranean rivers are generally oligotrophic and depend upon allochtenous sources of energy[17,18], as unlike the epigean streams, photosynthetic production is completely lacking here. On the other hand, the occurrence of leaf, debris and other organic matter is also negligible, which altogether restricts the aquatic subterranean biota. In such conditions the subterranean bats act as a major source of energy in various ways: (i) bat guano and (ii) debris/unconsumed food sources, etc.[9,19].

As discussed above the main entrance of the Mawkhyrdop cave is the main source of cave pollution due to which the main energy influx is derailed, threatening the life forms belonging to this zone. Further, the same stream is running all the way, till the other four streams join it and it eventually gets diluted (Figure 2). Relocation of bat colonies obviously depletes the extra energy sources, thus creating a hurdle for the existence of cavernicolous organisms, especially in the terrestrial zone. Finally, when we discuss about organisms living in the deepest zones of the cave, which are sensitive and highly adapted to the cave, we must keep in mind that even a minute variation in the ambient environmental conditions could bring them to the verge of extinction. Blasting in the surroundings may alter various factors of such deepest zones; such as alteration of the flow of water or creation of a small crack in the wall through which light could enter, etc. However, the energy influx for the cavernicolous organisms of this zone also depends on the geomicrobial input. Thus, it is a matter of investigation, whether the polluted surrounding water entering these zones via minute conduits exerts any effect on the life system of such specific species or not. In spite of quarrying effects, the domestic sewage is also making the cave atmosphere vulnerable; the accumulating non-degradable polythene pieces choke the conduits and affect the cave ecosystem, as well as the groundwater.

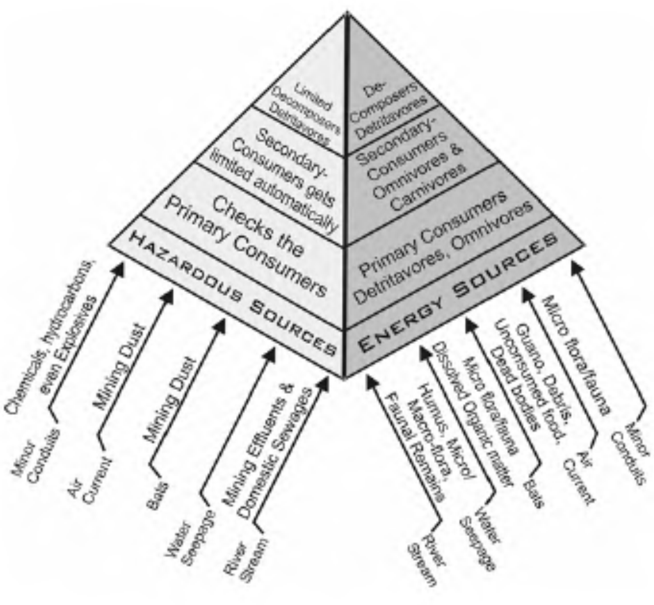

Figure 4. Possible sources of energy input and pollution sources in the Mawkhyrdop cave that neutralize energy inputs.

In 1947, a rich collection of cave biota was listed by Lindberg[20] from the Mawkhyrdop cave. This is the only report advocating the existence of biota in this cave before quarrying started in the cement factory. Thus, it is presumed that the biodiversity is waning in the cave. Now the question arises whether we should give up all the threatened cavernicolous species at the expense of upholding the socio-economic status of the state? At the beginning of this decade, the profit-making cement factory in this region, gave the highest production and dispatch of cement (exceeding 1.20 lakh tonnes), whereas by the end of the same decade we have to give up one of our most vulnerable gifts of the nature (the southern part of the cave has been greatly damaged). Both the factors, i.e. to save the biodiversity of the cave as well as to run mining works are important. However, to check the degradation of the cave as well as to protect the cave biota could be possible to some extent if some precautions are taken properly in the mining strategy; the ways have already been discussed elsewhere[21].

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