Q2. Write a detailed account of earthquakes and volcanic activities

Below is a postgraduate-level, exam-style answer with the requested subdivisions.

(a) Define earthquake and volcano, and explain their causes. *(4 marks)*

Definitions.

- **Earthquake:** A sudden release of elastic strain energy in the Earth's crust or upper mantle that radiates seismic waves. The release occurs when stress acting on a fault or fracture overcomes frictional resistance and causes abrupt slip. The point of rupture in the subsurface is the *hypocentre* (focus) and its projection on the surface is the *epicentre*.
- **Volcano:** A surface expression (edifice, vent or fissure) through which magma, volcanic gases and pyroclastic material are erupted from a subsurface magma reservoir. A volcano is the integrated surface manifestation of magmatic processes in the crust and upper mantle.

Causes — Earthquakes (mechanics and source processes).

- **Tectonic stress accumulation and elastic rebound.** In tectonic settings, differential forces (plate motions, regional stress fields) load faults. Elastic strain accumulates in surrounding rock until slip occurs; the sudden release and readjustment is the elastic-rebound process (Reid).
- **Fault types and failure modes.** Strike-slip, normal and reverse (thrust) faults represent different stress regimes; failure can be stick-slip (rapid large displacements) or stable creep (aseismic).
- **Seismic source parameters.** The seismic moment $M_0 = \mu A\bar{D}$ (rigidity μ, rupture area A, average slip $\bar{D}$) quantifies the physical size of the source; moment magnitude (Mw) is derived from M0 and scales with released energy.
- **Other causes.** Volcanic earthquakes (magma movement and pressurisation), collapse events (mines, caverns), induced seismicity (fluid injection, reservoir loading), and explosions also generate seismicity.

Causes — Volcanoes (magma generation and eruption triggers).

- **Magma generation mechanisms:**
  - **Decompression melting** at divergent boundaries or rift zones (adiabatic upwelling of mantle peridotite).
  - **Flux (hydration) melting** above subducting slabs where slab-derived volatiles lower the peridotite solidus producing arc magmas (andesitic compositions common).
  - **Heat-transfer or mantle plume melting** where thermal anomalies (plumes) or lithospheric heating induce partial melting.
- **Magma ascent and storage:** Magma ascends when buoyancy and overpressure overcome host-rock strength, segregates into dikes and sills, and may pond in crustal magma chambers where differentiation, degassing and crystallisation occur.
- **Eruption triggers:** Volatile exsolution (exsolving CO2, H2O), rapid pressurisation, magma recharge (new injection), dike propagation, or tectonic earthquake rupture can trigger an eruption.
- **Eruption style control:** Viscosity (function of silica content, temperature and crystal content) and volatile content control whether eruptions are effusive (low viscosity basaltic) or explosive (high viscosity andesite/rhyolite with abundant volatiles).

(b) Discuss the relationship between plate boundaries and these phenomena. *(3 marks)*

Divergent boundaries (mid-ocean ridges, continental rifts):

- Predominantly produce shallow, low-to-moderate magnitude earthquakes associated with normal faulting and transform offsets.
- Mantle upwelling and decompression melting generate basaltic magmas → extensive effusive volcanism and construction of new oceanic crust (e.g., Mid-Atlantic Ridge, East African Rift volcanism).

Convergent boundaries (subduction zones):

- Host the largest earthquakes (megathrusts) due to long, locked plate interfaces (e.g., 1960 Chile, 2011 Tōhoku). Seismicity spans shallow to very deep focal depths (Wadati–Benioff zone) due to sinking slabs.
- Volcanism is volatiles-rich arc magmatism (andesitic to dacitic), produced by flux melting from slab dehydration and mantle wedge processes. Volcanic arcs and associated orogenic processes are typical (e.g., Andes, Japan, Cascades).
- Subduction settings are also primary tsunami sources due to vertical seafloor displacement during megathrust ruptures.

Transform boundaries:

- Characterised by strike-slip faulting with frequent shallow earthquakes (e.g., San Andreas system). They typically lack sustained magmatism except where local extensional steps or crustal heterogeneities permit magma emplacement.

Intraplate and plume-related settings:

- **Hotspots/plumes** produce intraplate volcanism (e.g., Hawaiʻi) and move relative to plates, creating age-progressive volcanic chains. Earthquakes are generally less frequent but can occur due to volcanic processes or regional stress.
- **Continental rifts** (e.g., East African Rift) combine divergent-type magmatism with significant seismicity.

Synthesis: Plate boundary type largely controls earthquake depth distribution, dominant fault mechanism and magma genesis pathways; however, local lithospheric structure, pre-existing faults, and mantle dynamics modulate the detailed expression of seismicity and volcanism.

(c) Mention the environmental impacts of earthquakes and volcanic eruptions. *(3 marks)*

Immediate physical impacts — earthquakes:

- **Ground shaking and structural collapse:** Primary cause of human fatalities and infrastructure loss.
- **Surface rupture and co-seismic deformation:** Permanent offset of the ground, fault scarps.
- **Tsunamis:** Generated by rapid seafloor displacement in submarine megathrusts; coastal inundation causes catastrophic loss (e.g., 2004 Sumatra–Andaman, 2011 Tōhoku).
- **Landslides and rockfalls:** Triggered on steep slopes, causing burial of settlements and river damming.

- **Liquefaction:** Water-saturated sediments lose strength, damaging foundations and buried utilities.

Immediate physical impacts — volcanic eruptions:

- **Pyroclastic density currents (PDCs):** Fast, extremely destructive hot gas-and-tephra flows that obliterate everything in their path (e.g., 1902 Mt. Pelée).
- **Ashfall:** Widespread deposition that collapses roofs, contaminates water supplies, disrupts agriculture and aviation, and causes respiratory illness.
- **Lava flows and ballistic ejecta:** Locally destructive; lava modifies topography and can sever infrastructure.
- **Lahars:** Volcanic mudflows mobilised by ash and water (rainfall or glacier melt), travel large distances and bury valleys.

Short- to medium-term environmental and climatic effects:

- **Atmospheric aerosols and climate forcing:** Injection of SO_2 and ash into the stratosphere produces sulfate aerosols that increase planetary albedo, causing short-term (1–3 yr) global cooling; a classic example is the 1991 Mt. Pinatubo eruption which produced a measurable cooling of global surface temperatures for a few years.
- **Alteration of atmospheric chemistry:** Heterogeneous reactions on volcanic aerosols can influence ozone, and emitted halogens may contribute to localized ozone depletion.

Hydrological, ecological and biogeochemical consequences:

- **Water contamination:** Ash and suspended sediments alter water chemistry; heavy metals and acidification may follow.
- **Ecosystem disturbance and succession:** Habitat destruction is followed by primary succession on fresh volcanic deposits; ash inputs can initially reduce productivity but later supply nutrients (P, K) that enhance soil fertility over decades.
- **Geomorphic change:** Deposition, erosion and river re-routing reshape landscapes; volcanism can build islands or dam rivers, altering long-term drainage.

Socio-economic and public-health impacts:

- **Human casualties, displacement and economic loss:** Collapse of housing, loss of livelihoods, interruption of services and long-term reconstruction burdens.
- **Secondary hazards and health:** Fires, disease outbreaks in displaced populations, respiratory and ocular irritation from ash, CO_2 or H_2S accumulation in low-lying areas (volcanic CO_2 asphyxiation events).
- **Long-term climate/ecosystem crises:** Very large igneous province (LIP) events are linked to past mass extinctions and profound climatic perturbations on geological timescales.

Mitigation / adaptation implications (brief):
Understanding processes and impacts underpins hazard mapping, land-use planning, building codes, seismic and volcanic monitoring (seismic networks, GNSS, InSAR, gas measurements), early-warning systems (earthquake early warning, tsunami alerts), and community preparedness — all essential to reduce environmental and societal losses.

Concluding remark.
Earthquakes and volcanism are integral expressions of Earth’s internal dynamics. Their study spans mechanics of rupture and magma physics to atmospheric and ecological consequences — a

multidisciplinary field critical to hazard science, risk mitigation and understanding Earth system interactions.