

## An e-Environment System for Socio-economic Sustainability and National Security

### System e-środowiska dla zrównowżenia społeczno-ekonomicznego i bezpieczeństwa narodowego

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#### **Abstract**

Though there are adequate institutional frameworks and legal instruments for the protection of the Sub-Saharan African environment, their impact on the development and conservation (protection) of the environment leaves much to be desired. This assertion is substantiated by the reality that in spite of these regulatory frameworks, the environment is largely degraded with negative ramifications for the twin goals of attaining sustainable socio-economic advancement and realization of environmental rights. Both national and regional state of environment (SoE) reports show that degradation is apparent. It is worthy of mention that almost all African countries have ratified and domesticated the various regional and subregional environmental agreements. Efforts to solve the puzzle have revealed that corruption and environmental degradation in Sub-Saharan Africa are closely linked. Financial impropriety in ecological funds management, poorly equipped environmental protection institutions, and inadequate citizens' environmental management awareness campaigns are outcomes of corruption in the public sector. Since corruption thrives in the absence of transparency and accountability, this study proposes a cutting-edge technology-based solution that promotes participatory environmental accountability using an e-Environment system. The web-based multi-tier e-Environment system will empower both citizens and government officials to deliberate online real-time on environmental policies, programmes and projects to be embarked upon. Both parties will equally put forward proposals on the use of tax payers' money in the environment sector while monitoring discrepancies between amount budgeted, amount released and actual amount spent. We applied design and software engineering skills to actualize the proposed solution. Using Nigeria as case study, our research methodology comprised literature review, requirements gathering, design of proposed solution using universal modelling language (UML) and development/implementation on the Microsoft SharePoint platform. In view of our determination to evolve a zero-defect software, we applied Cleanroom Software Engineering techniques. The outcome obtained so far has proved that the model supports our expectations. The system is not only practical, but ecologically sound. It is anticipated that the full-scale implementation of such an enterprise e-Environment system will decrease the current tide of corruption in the environment sector, mitigate environmental degradation and by extension, reduce social-economic tensions and guarantee national security.

**Key words:** Cleanroom Software Engineering, corruption, e-Environment, environmental degradation, socio-economic, sustainability, national security

## Streszczenie

Chociaż w Afryce Subsaharyjskiej istnieją odpowiednie ramy instytucjonalne i instrumenty prawne dla ochrony środowiska, ich wpływ na zachowanie (ochronę) środowiska naturalnego pozostawia wiele do życzenia. Pomimo istniejących ram regulacyjnych, środowisko jest tu w dużej mierze zdegradowane, co negatywnie wpływa na możliwość osiągnięcia podwójnego celu: osiągnięcia zrównoważonego rozwoju społeczno-gospodarczego i ochrony środowiska. Zarówno krajowe, jak i regionalne raporty o stanie środowiska (SoE) pokazują, że degradacja ma miejsce. Warto wspomnieć, że prawie wszystkie kraje afrykańskie ratyfikowały i wprowadziły różne regionalne i subregionalne porozumienia dotyczące ochrony środowiska. Próby zmierzające do uporządkowania sytuacji pokazały, że korupcja i degradacja środowiska w Afryce Subsaharyjskiej są ze sobą ściśle powiązane. Niepewność finansowa odnosząca się do zarządzania funduszami ekologicznymi, słabo wyposażone instytucje ochrony środowiska oraz nieodpowiednie kampanie informacyjne na temat zarządzania środowiskiem w zakresie ochrony środowiska są wynikiem korupcji w sektorze publicznym. Ponieważ z braku przejrzystości i odpowiedzialności korupcja kwitnie, niniejsze badanie proponuje nowoczesne rozwiązanie, które promuje partycypacyjną odpowiedzialność za środowisko z wykorzystaniem e-Środowiska. Wielowarstwowy system e-Środowiska, oparty na Internecie, umożliwi zarówno obywatelom, jak i urzędnikom państwowym, dyskusję w czasie rzeczywistym odnoszącą się do polityki dotyczącej ochrony środowiska, a także wszelkich przygotowywanych programów i projektów. Obie strony będą również wysuwać propozycje dotyczące wykorzystania pieniędzy podatników w sektorze środowiskowym, przy jednoczesnym monitorowaniu rozbieżności między kwotą przewidzianą w budżecie, a faktyczną wydaną. Zastosowaliśmy umiejętności projektowe i programistyczne, aby zaktualizować proponowane rozwiązanie. Wykorzystując studium przypadku w Nigerii, nasza metodologia badań obejmowała przegląd literatury, określenie wymagań, projektowanie proponowanego rozwiązania z wykorzystaniem uniwersalnego języka modelowania (UML) oraz opracowanie / wdrożenie realizowane na platformie Microsoft SharePoint. W związku z naszą determinacją odnoszącą się do opracowania w pełni funkcjonalnego oprogramowania, zastosowaliśmy techniki Cleanroom Software Engineering. Uzyskane wyniki dowiodły, że model ten spełnia nasze oczekiwania. System jest nie tylko praktyczny, ale także ekologiczny. Przewiduje się, że pełne wdrożenie takiego systemu e-Środowiska w przedsiębiorstwie doprowadzi do zmniejszenia obecnej fali korupcji w sektorze środowiskowym, zmniejszy degradację środowiska, a poprzez to zmniejszy napięcia społeczno-gospodarcze i zapewni bezpieczeństwo narodowe.

**Słowa kluczowe:** Cleanroom Software Engineering, korupcja, E-środowisko, degradacja środowiska, społeczeństwo, ekonomia, zrównoważoność, bezpieczeństwo narodowe

## 1. Introduction

Amid concerns that climate change is the defining threat of the century, measures are being put in place globally to mitigate its effect. In Africa, humanitarian crisis linked to environmental challenges such as flash flood, desert encroachment, coastal erosion, oil spillage and gully erosion continues to be a threat to national security (Ewharieme, Cocodia, 2011; Akokpari 2007). The reason not far-fetched: economic livelihoods are threatened by ecological distortions. The environment is of strategic imperative to Africa's sustainable development drive. The Environmental Initiative of NEPAD (New Partnership for Africa's Development) has acknowledged that a productive and healthy environment is a sine qua non in that it is critical to the creation of the ecological and social base as a veritable platform for the partnership to thrive. Before the inception of NEPAD, African leaders had acknowledged that the environment and its resources are relevant to the continent's development and therefore put measures in place for its conservation and protection as confirmed at the *Algiers Convention* which adopted the *African Convention on the Conservation of Nature and Natural Re-*

*sources* in 1968 (Amechi, 2009). Since then, other regional and subregional environmental agreements have come into the fray such as the *Nairobi Convention for the Protection, Management and Development of Marine and Coastal Environment of the Eastern Africa Region*, *Convention for Cooperation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region*, and *Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa*.

Equally at the national level, there has been actions – many environmental initiatives have been adopted to facilitate socio-economic development and protect the environment. Moreover, many human rights initiatives in Africa have sufficiently made provision for environment right that ensures positive contribution to the promotion of socioeconomic development in the region. Specifically, people have the right to satisfactory environment that supports their development as enshrined in article 24 of the *African Charter on Human and Peoples' Rights*.

It is worthy of mention that almost all African countries have ratified and domesticated these charters.

For instance, the *South African Constitution* in section 24 provides that the health or wellbeing of everyone shall be protected by the right to a non-harmful environment. In like manner, for the benefit of present and future generations, the environment has to be protected via well thought-out and secured ecologically sustainable development. Another means is through the efficient deployment of natural resources even as social and economic development is promoted.

Despite the presence of many legal instruments/ institutional frameworks for environmental protection, expectations on their impact on the conservation or protection of the Sub-Saharan African environment have been cut short. Hence, the environment remains largely degraded with negative aftermaths for the realization of the right to environment and attainment of sustainable development. State of Environment (SoE) reports at national and regional levels such as the 2006 South African SoE and 2003 Kenyan SoE provide ample proofs of monumental degradation. Since it has been established that the environmental devastation problem and associated non-realization of right to environment on the continent is not as a result of absence of regulatory frameworks, we therefore beamed our searchlight somewhere else. As alluded to in the literature by some authors, corruption exists in Africa (Okewu and Okewu, 2015) and it has continued to aggravate environmental degradation on the continent (Ewharieme, Cocodia, 2011). Mismanagement of ecological funds, poorly equipped environmental protection institutions, inadequate citizens' environmental management awareness campaigns are some of the fallouts of corruption in the public sector. Bribes and illicit deals don't only fleece away resources from the public coffers, they impede economic advancement and ecological justice, providing fertile grounds for social tension and national insecurity. Using expert opinions across the world, Transparency International, the global coalition against corruption, gauged the perceived levels of public sector corruption globally in its *2014 Corruption Perceptions Index*. The index produced a disturbing picture of African countries. Globally, above two-thirds of countries scored below 50. Also, not a single country got a perfect score. With a scale of 0 (highly corrupt) to 100 (very clean), the fact that 92% of African countries scored below 50 is a pointer to the phenomenal corruption in the region (Transparency International..., 2014). As concerning as corruption is to all countries, a poor score indicates widespread bribery, inadequate sanction for corruption and non-functional public institutions that are unable to respond to citizens' needs. Countries at the bottom of the index have to take stringent anti-corruption measures to impact positively on the lives of their people just as countries at the top should oblige not to export corrupt practices to developing countries (Transparency International..., 2014).

This paper proffers a technology-based approach to handle the challenge of corruption-induced environmental devastation in a bid to enhance environmental sustainability and national security in Sub-Saharan African countries. Our strategy is to provide participatory environmental accountability forum through an online real-time e-Environment system that is web-based. This is against the background that corruption thrives in the absence of transparency and accountability (Okewu and Okewu, 2015). The solution empowers the citizenry and government to engage in constructive discussions on how public finance for the environment sector is utilized. It is a confluence for all environment stakeholders to cross-fertilize ideas on appropriate policies, programmes and services that would best serve the ecological governance of their country. With e-Environment, financial prudence in the public sector is promoted, fiscal discipline entrenched, corruption levels are checked and resources freed up to cater adequately for protecting the environment and realizing the right to it.

Typically, African countries share a lot in common in context of environmental practices, operations and structure even though they have their peculiarities. Therefore, modelling and developing software using a reuse-based approach that is relevant to many countries with minimal errors will be of significant benefits. Cleanroom software engineering (CSE) is a virtual error-free paradigm of developing software where environments and processes are meticulously examined, monitored and controlled for any errors (Head, 1994; Mills et al., 1987). In the event a defect is found, it is classified to ascertain failed process and measures taken to avert such failure subsequently. The faulty process is amended and rerun while the original product is discarded. In CSE, unit testing is not required (Pressman, 2009) and this implies reusable components from tested and trusted vendor products that engenders users and developers confidence are of strategic imperative (Sommerville, 2011; Okewu, Daramola, 2014).

In this paper, we present a report of a study of the use of CSE for designing and developing an e-Environment system for Africa with Nigeria as test bed. It practically investigates the nexus between corruption, environmental sustainability and national security that have been alluded to in the literature by some authors (Akokpari, 2007; Amechi, 2009; Kakonge, 2006). Nonetheless, few reports on practical application of CSE in the industry exist in the literature. Kaur (2011) and Selby et al. (1987) argue that more empirical evidence of the application of CSE is required by the cleanroom software engineering research community. Moreover, the fact remains that renowned international conferences in the field of environmental science and technology such as the *International Conference on Environmental Science and Technology* and *European Industrial Symposium on Cleanroom Software Engineering* are cont-

inuously advocating for more case studies in their calls for papers. As a contribution, we seek to enrich the body of knowledge in environmental science and technology by an empirical evidence of CSE application in Nigeria. This is of particular significance in that it is rare to come across empirical evidence of an e-Environment system with origin in Africa.

The remaining segment of this article is composed as follows: in Section 2, the focus is on related work and background of study; the methodology and selected case study are presented in Section 3; section 4 discusses results; and we conclude the paper in section 5.

## 2. Background and framework

### A. Climate change in Africa

Climate change in Africa is of growing concern to stakeholders within and outside the continent. Schneider et al. (2007) stressed that Africa is probably the most vulnerable to climate change amidst all the continents. The same sentiment was shared by Boko et al. (2007) who forecasted that in many African countries and regions, there is likelihood that food security, water availability and agricultural production would be gravely hampered by the vagaries of climate change.

In East Africa, the worst drought in many years was experienced in 2011 owing to interrupted seasonal rains for two seasons in a row. Overtime, the precipitation rate of many areas within the region during the rainy season has dwindled considerably with less than 30% of the average rainfall for the time period 1995-2010. Researchers in 2012 uncovered a connect between changes in the sea surface temperature of the tropical Pacific Ocean and the region's low rainfall. They explained that the disruption of long rains was as a result of this relationship. This unique discovery is already aiding emergency preparedness and improved forecasts.

Sahel region has its fare share – it is yoking under climate change vulnerabilities and environmental risks. It has been pointed out that between 1970 and 2010, a temperature rise in excess of 1°C was experienced by 15 per cent of the population of Sahel region. Equally, flooding has increased in severity and frequency just as it is experiencing below average mean seasonal rainfall. For instance, in the 17 Sahel region countries, about five floods have impacted on 54% of the population since 1985. Furthermore, in 2012, there were severe drought conditions. So far, regional governments have responded with strategies to deescalate the environmental challenge.

### B. Sustainable development and national security

Incidences of terrorism, kidnapping, youth restiveness, militancy, among others are recurring decimals in developing economies (Okewu et al., 2017). Reason being that there are limited options for survival; hence massive unemployment and underemploy-

ment which translate into low purchasing power. The dearth of critical infrastructure such as power, transportation system, water, etc means real sectors of the economy such as agriculture, education, manufacturing and others like construction, extractive and service sectors are underdeveloped for the engagement of productive minds. Consequently, overall national productivity is low resulting in downward looking economic indicators such as GDP, interest rate, inflation rate, unemployment rate, and exchange rate. Caught in the web of poverty and misery, citizens begin to agitate which finds expression in social vices such as ethno-religious crisis, terrorism, kidnapping, militancy, among others. All these agitations pose serious national security threats and in extreme case, humanitarian crisis erupts. There is strong evidence that environmental degradation and devastation can destroy people's livelihoods and inflict insecurity in a nation. For example, some developing economies such as Nigeria that have not been able to manage their oil and gas resources very well have had to deal with oil spillage over the years with attendant destruction of the ecosystem of communities where oil exploration is taken place. Oil spillage does not only destroy the fertility of the land but also destroys aquatic lives upon which the people depend for their sustainability. Gas flaring also releases harmful gases into the atmosphere, occasioning global warming. In frustration, citizens device negative strategies for survival, exploring options such as oil bunkering, illegal refining, outright pipeline vandalism, embracing piracy and kidnapping and in extreme cases, taking up arms as militants. The Niger Delta region of Nigeria that has been embroiled in crises over the years is a case in point. Conversely, in developed countries where such resources have been optimally harnessed, sustained growth and development is the outcome as there is positive multiplier effects on all sectors of the economy. There is therefore need for both multinational corporations and governments to pay special attention to ecological justice as a way of ensuring sustainable development and guaranteeing national peace and security. Despite efforts made in the past to protect and preserve the environment, brazen public and private sectors corruption has made proper ecological funds management a mirage (Ewharieme, Cocodia, 2011).

### C. Corruption incidence and measurement in Africa

As observed by Okewu and Okewu (2015), in order to manage corruption successfully in Africa, there is need to understand its depth and breadth. The menace is real and of monumental threat to the socio-economic and political advancement of the continent. Against the background that measuring corruption will enable us to manage it more effectively and efficiently in the context of environmental justice, we examined corruption incidence in Africa for a period of 3 years (2012-2014) relying on data from the global corruption perception index by the global cor-

ruption watchdog, Transparency International. Our findings indicate that Africa is the poster child for corruption and poor governance. Of the 175 countries measured for the 3-year period, data clearly indicated that vast majority of African countries were at the bottom of the table, a segment classified as highly corrupt. Table 1 is a summary of the corruption perceptions index 2014 by region measured on a scale of 0 (highly corrupt) to 100 (very clean).

Table 1. Corruption Perception Index 2014, results by region, source: Transparency International Corruption Perception Index 2014

Region	Average score	Top (Cleanest Country)	Bottom (most corrupt country)	% of countries that scored below 50
Americas	45	Canada (83)	Haiti, Venezuela (19)	68%
EU and Western Europe	66	Denmark (92)	Greece, Italy, Romania (43)	16%
Sub-Saharan Africa	33	Botswana (63)	Somalia (8)	92%
Eastern Europe and Central Asia	33	Georgia (52)	Turkmenistan (17)	95%
Middle East and North Africa	38	United Arab Emirates (70)	Sudan (11)	84%
Asia Pacific	43	New Zealand (91)	North Korea (8)	64%

As shown above (Table 1), there is ample statistical evidence that Sub-Saharan Africa is among the most corrupt regions in the world, having tied with the Eastern Europe and Central Asia region on average score of 33 with 92% of its countries scoring below 50. Even then, one of the most corrupt nations, Somalia, is in Sub-Saharan Africa tying with only North Korea at a corruption score of 8. Of the 175 countries gauged in 2014, Denmark emerged the cleanest with score of 92.

To corroborate these statistics and global perspective with ground-level perspective, virtually all institutions in Africa ranging from legislature to judiciary are under the yoke of corruption and mismanagement of public resources (Okewu and Okewu, 2015). A case in point: despite the pervasive poverty in African countries like Nigeria and Kenya, the cost of governance is high. In a comparative study, Tom and Attai (2014) provided statistical evidence as shown in Table 2, comparing the emoluments of legislators and their minimum wages in six countries, Nigeria and Kenya inclusive.

Going by the above statistics, it is concerning that politicians in Africa (Nigeria and Kenya) compared

to their counterparts in developed societies, are taking advantage of the already impoverished masses. For instance, it is breathtaking that while only 0.47% and 0.13% (0.18%) of legislators' pay constitute minimum wage in Kenya and Nigeria respectively, the figures are 8.6%, 21.68% and 26.73% in US, UK and France respectively. Juxtaposing these statistics with those of Transparency International in 2014 corruption index, we observed that Nigeria and Kenya respectively occupy distant 136 and 145 out of the 175 countries measured. Since, these legislature pay structures don't reflect the economic realities of these African countries, it is safe to say that politics in Africa favours political officials to the detriment of the masses. Little wonder then that would-be political office holders would do anything, including corrupt practices, to secure position at all cost. And once there, they explore and exploit public sector finance, including ecological funds, for personal aggrandizements. An inclusive dialogue platform such as the e-Environment system that empowers the masses to air their concerns on environmental budgets, policies, programmes and services will certainly checkmate these fiscal excesses.

To substantiate the sentiment in some quarters that corruption has assumed the status of a culture in Africa, both the highly and lowly placed citizens engage in the practice with impunity. Overtime, the weakening of institutions has made things worse as prosecution of offenders is now a mirage. Nonetheless, the judicial system, home and abroad, has been instrumental in bringing to book some high profile corruption cases in Africa. This situation calls for additional and complimentary urgent measures to get Africa out of the woods. One of such measures we proposed in this study is the technology approach (e-Environment) which provides a technique of enhancing participatory environmental accountability in ecological governance.

#### D. Cleanroom Software Engineering

One doctrine of cleanroom software engineering (CSE) is ensure virtual error-free software by eliminating unit testing as much as possible (Head, 1994; Linger, 1993; Linger, Tramell, 1996). Hence, six-sigma (highly quality) software could be achieved by focusing on design and coding. One practical way to achieve this is to use tested and trusted components from established vendors (Sommerville, 2011) such as embedded in Microsoft SharePoint (Okewu, Dar-amola, 2014). CSE is a metaphor derived from integrated circuit manufacturing. In this domain, conscious and concerted efforts are made to ensure the environment for large-scale integrated circuits manufacturing is free from amoebas, dust, flecks of skin, and the likes. The environment and processes are meticulously controlled just as the results are monitored constantly. Any defect that occurs is not seen as defect in the product but rather defect in the process. To confirm the process failure that produced

Table 2. Comparison of legislators' pay in six countries

Country	Legislators' pay monthly	Legislators' pay annually	Minimum wage monthly	Minimum wage annually	% of legislators' pay that is minimum wage
Nigeria	Senate N15.2m Reps N10.6m (\$69,533)	Senate N182m Reps N127m (\$834,402)	N18,000 (\$118.15)	N234,000 (\$1,536) inclusive of 13th month salary	0.13% 0.18%
India	N305,058 (\$1,999)	N3.7m (\$23,988)	Varies from state to state, sector to sector	-	-
US	N2.2m (\$14,500)	N26.5m (\$174,000)	N191,667 (\$1,257)	N2.3m (\$15,080)	8.6%
UK	N1.3m (\$8,686)	N15.9m (\$104,228)	N283,333 (\$1,883)	N3.4m (\$22,597)	21.68%
Sweden	N1.2m	N14.1m	Set by annual collec- tive bargaining deal	-	-
France	N1.02m (\$6,754)	N12.3m (\$81,951)	N275,433 (\$1,805)	N3.3m (\$21,664)	26.73%
Kenya	N2.2m (\$14,543)	N26.7m (\$175,000)	N10,534 (\$6,917)	N126,413 (\$830)	0.4%

the defects, they (defects) are subsequently characterized, debugged and rerun. This leads to a regenerated product just as the original defective product is discarded (Mills et al., 1987; Linger, 1993).

The philosophy of CSE is similar to the cleanroom process of integrated circuit manufacturing. Environments and processes are scrupulously monitored and controlled for defect. The presence of defects means a single or multiple processes contain such defects. The defects could exist in the inspection techniques, specification process, or the design methodology used. The code module or source file typically does not harbour defects. To determine the failed process, each defect is categorized. The classification also help in preventing failure. After correcting the failing process, it is rerun and the original product discarded. The original product is then discarded. As a result, the traditional life cycle is different from the life cycle of a cleanroom project. It is widely acknowledged that the traditional 40-20-40 post investigation life cycle is composed of 40 per cent design, 20 percent code, and 40 percent unit testing (Pressman, 2009). Thereafter, the product undergoes integration testing. On the other hand, cleanroom patronizes an 80-20 life cycle which entails designing is 80% while coding takes 20% of the life cycle. Thereafter, the integration testing is presented with the untested and unexecuted product amid expectation that it will work. Should it fail, ways of improving the process are determined by examining the defects. The improved process is then used to regenerate the defective and discarded product. This way, unit testing is conspicuously absent in cleanroom software engineering (Sommerville, 2011).

E. Innovative System and Inclusive Environmental Protection and Development Sustainable protection and development of the African ecosystem should be collective responsibility of government and the citizenry alike. In this light, a major consideration is a platform that drives real-time dialogue between lead-

ers and the led such that public expenditure on proposals and implementations of environmental initiatives should be well scrutinized for fiscal discipline in the environment sector. Our proposal of a web-based online real-time e-Environment system is part of efforts to deploy innovative system for inclusive environmental protection and development. It is anticipated that e-Environment will empower government ministries, departments and agencies (MDAs) on one hand and the citizenry on the other hand to have fruitful deliberations on how environmental budgets such as ecological funds should be spent. Besides the conversation, it will provide a monitoring and compliance scheme such that citizens are able to monitor discrepancies between amount budgeted, amount released and actual amount spent on environmental management programmes. This way, endemic corruption in the sector can be mitigated if not eliminated.

#### F. Related work

Previous efforts in the literature that are related to corruption and environmental management in Africa are as follows.

Ewharieme and Cocodia (2011) x-rayed urban development in Nigeria vis-a-vis ecological governance with particular focus on the Niger Delta region reputed for its environmental degradation struggles. The authors noted that owing to the cardinal role of oil in Nigeria's Niger Delta political economy over the years, public discourse has centered on issues of oil-related environmental degradation. But they observed that besides oil, corruption has aggravated the situation, wrecking havoc on the environment and making the oil-induced environmental assaults worse. The paper also examined how issues such as ecological menaces are treated and the impact of corruption in leaving them unattended to. Despite providing linkages between corruption and worsening environmental degradation in Nigeria, the study fell short of suggesting how ICT could be used to

tackle environmental challenges in a bid to guarantee national security. This is the chief motivation for our study.

Vuuren (2014) studied corruption in South Africa in the context of its nature and degree. Though laws and institutions have been developed in South Africa that provide measured response at the national level to cases of corruption, the researcher observed that the law is applied inconsistently giving leeway to corruption to escalate levels of economic inequality. The author stressed that the solutions to South Africa's problems should embrace institutions, open society and destruction of corrupt elite networks. Else, inequality will deepen and anti-democratic forces will hold sway. It is worth mentioning that our proposal for an e-Environment solution is to drive open and online real-time conversations between citizens and government officials on how public finance is utilized with particular reference to the environment sector.

Kakonge (2006) focused on the challenges confronting the internalization and institutionalization of Environmental Impact Assessment (EIA) process. Amid concerns that environmental planning is yet to gain ground in Sub-Saharan Africa, the author stressed that countries can adapt and benefit from the process of Environmental Impact Assessment (EIA). A number of issues that have impeded the full utilization of the EIA process were outlined as scanty public participation, unreliable and inadequate data, dearth of experience and national expertise in EIA, weak enforcement, defective environmental legislation, and limited impact coverage. Measures to correct the situation were highlighted as complying with international agreements, broadening ownership of EIA, supporting public sensitization to simplify the EIA process, scaling up funding of EIA studies for government funded-projects, facilitating good governance and mitigating corruption. In conclusion, the researcher advised that more resources and intensified efforts would be needed at all levels of the development planning process to integrate EIA for the realization of full benefits. Though the study did not highlight the role of ICT in environmental planning, the author agreed that corruption impacts on environmental impact assessment.

Amechi (2009) approached the subject from a legal point of view, emphasizing the nexus between sustainable development and the environment. The article proffered a comprehensive approach to handling the challenge of environmental devastation as part of efforts to actualize the right to environment and attain sustainable development in Africa. Contributory factors to environmental degradation on the continent were outlined. Recommendations on how the international community could help African countries to protect their environment and facilitate the realization of the right to environment were made. The author was concerned that in spite of Af-

rica's many institutional frameworks and legal instruments for environmental protection, much still needs to be done on its conservation. Although the study did not suggest a technological solution for dealing with environmental challenge, it drew a link between ecological governance, economic sustainability and national security.

Akokpali (2007) opined that human insecurity has reached unprecedented levels in Africa, especially Sub-Saharan Africa. Apart from having large portion of its population living below poverty line, the continent is bedevilled with conflict and instability. In addition, Africa has high disease burden even as food and nutritional inadequacies have assumed phenomenal proportions. He cautioned that the continent remains vulnerable to drought, even as environmental degradation is on the increase; typified by deforestation, desertification, soil erosion, oil spillage, pollution, and depleting fish and game stocks. The paper added that ecological problems in Africa are made worse by inability of African governments to establish credible environmental regimes coupled with their willingness to trade the environment for scarce foreign exchange. The combination of all these factors presents Sub-Saharan Africa as an indisputable region for human insecurity. The study sufficiently drew a connect between environmental injustice and national (human) security even though it was silent of role of ICT in entrenching ecological governance.

Head (1994) shared practical experience from the application of cleanroom software engineering (CSE) at Hewlett-Packard (HP). The paper confirmed that CSE has demonstrated capability of producing non-defective software and remarkable results were achieved when applied in a typical HP environment. The author emphasized that CSE is possibly the easiest methodology and most repeatable technique of all software development methodologies used for producing six-sigma (high quality) software system. In the early 1980s, CSE emerged, originating from IBM Corporation's Federal Systems Division. Although the only application areas of six-sigma were initially manufacturing processes and hardware reliability, it has been realized it could be applicable to software quality. The six-sigma value is put at 3.4 parts per million (3.4 ppm) defective and the philosophy is that long-term reliability requires more refined design that guarantees the ruggedness of the emergent product in terms of enduring stress without failing. Despite sharing industrial experience of using CSE, it was not applied in an African context to tackle the problem of ecological degradation, socio-economic sustainability and national security.

In a nutshell, none of the reviewed literature focused on applying CSE to resolving corruption-driven environmental degradation for socio-economic sustainability and national security. We therefore instituted a study in this regard.

### III. Methodology – Cleanroom Software Engineering for the e-Environment

The study used Nigeria as a test bed since environmental degradation is an existential threat in the country – the Niger Delta region in particular (Ewharieme, Cocodia, 2011). In addition, its nature and scale are a microcosm of Africa's ecological challenges. It is on record that Nigeria was the first country in Africa to have an environmental protection agency with the inauguration of the Federal Environmental Protection Agency (FEPA) in 1988. Prior to the 1987 toxic waste dumping at Koko village in Delta State, Nigeria could not manage demanding environmental crisis. This is because environmental laws and regulations could not be enforced for protecting the mother earth owing to the dearth of institutional templates.

Following the Koko toxic waste scandal, the Federal Government came up with the 1988 Harmful Waste Decree 42. This expedited the setting up of the Federal Environmental Protection Agency (FEPA) based on Decree 58 of 1988 and the amended Decree 59 of 1992.

The onus of environmental management and protection then rested on FEPA. However, FEPA has metamorphosed into a parastatal in the Federal Ministry of Environment called National Environmental Standards and Regulations Enforcement Agency (NESREA).

With the understanding that Nigeria's environmental experience represents in microcosm the African ecological experience, we used the country as case study and for industrial experience. We developed the e-Environment system and tested it. The proof of technology was done using Microsoft SharePoint while the underlying theoretical framework was cleanroom software engineering (CSE) with real-life environmental data from Nigeria to enhance confidence in our work (Pressman, 2000; Sommerville, 2011). Guided by the CSE life cycle activities (specification, development and certification), the study progressed. We reviewed literature, gathered requirements, designed the proposed solution using unified modelling language (Martin, 1998), developed and implemented it on the Microsoft SharePoint platform. We then verified and validated the solution and discussed our findings.

#### A. Specification

Requirements were gathered, analyzed and system modeled using unified modelling language (UML). The researchers, using gathered requirements, summarized the cross-cutting functional requirements of the proposed solution in Table 3.

Deployment diagram was also used to model the proposed e-Environment solution. It comprised personal computer (PC), third party tool such as phone, online payment device, among others. Users can

view outcome on PC and as well on phone. It is anticipated that even with intensity of environmental awareness campaign and government regulation and enforcement systems, some citizens may default and would be sanctioned by way of paying fines. We therefore included an online payment component. This way, defaulters can make payment online real-time directly to appropriate and authorized accounts operated by environmental agencies like NESREA.

Table 3. Cross-cutting functional requirements

Req. ID	Requirement	Brief Description
R01	Add environmental information	The system shall allow authorized users to add environmental information to the database depending on assigned rights and privileges.
R02	Access environmental information	The system shall allow authorized users to access environmental information from the database in accordance with assigned rights and privileges.
R03	Edit environmental information	The system shall allow authorized users to edit environmental information on the database in line with assigned rights and privileges.
R04	Delete environmental information	The system shall allow authorized users to delete environmental information from the database contingent upon rights and privileges assigned.

#### B. Development

Microsoft SharePoint was used as the development platform. This is against the backdrop that reusable components from an established vendor's (like Microsoft) product that is well tested and trusted promotes confidence of users and developers (Sommerville, 2011; Okewu, Daramola, 2014) that the proposed solution would be virtually error-free in tandem with the ideology of cleanroom software engineering (Kaur, 2011; Linger, 1993). Fault eradication apart, integrating reusable components in the development effort fast-tracks software development. Also, the web-based multi-tier clustered architecture of Microsoft SharePoint supports quality requirements and emergent properties of the e-Environment system – usability, availability, reliability, fault tolerance, maintainability, among others (Pressman, 2009).

Ahead of development and implementation on the web-based n-tier Microsoft SharePoint development platform, we evolved an algorithm for the proposed system.

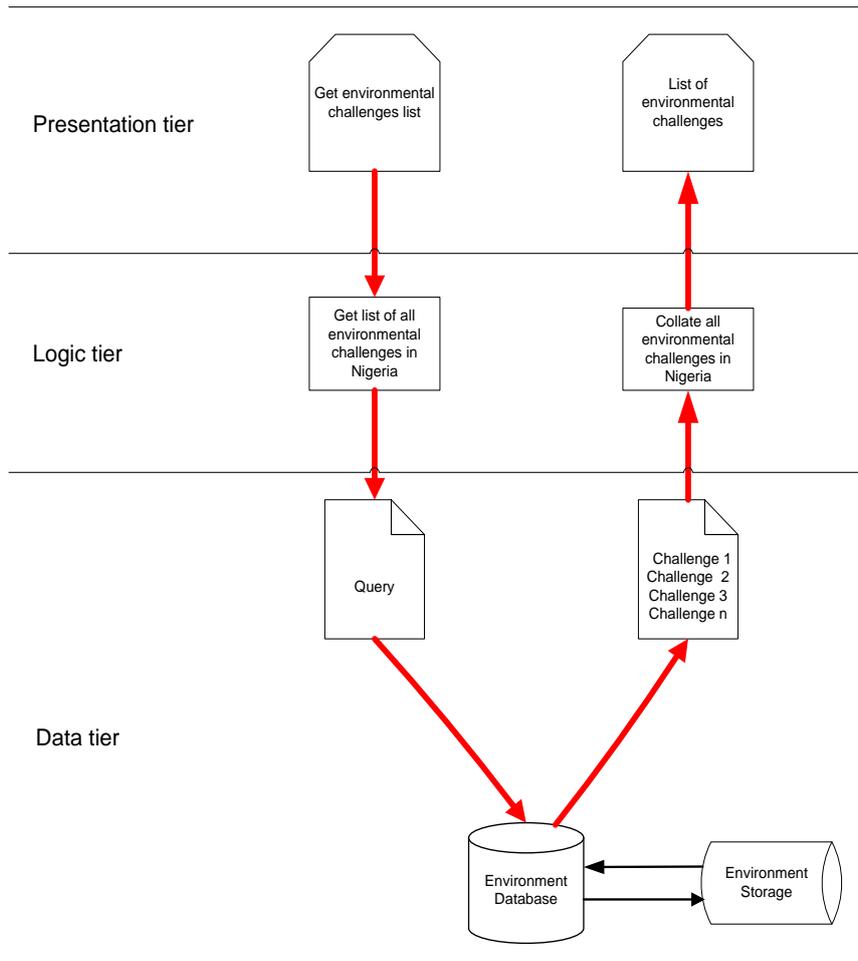


Figure 1. Visual overview of the 3-tiered e-Environment architecture

The e-Environment software architecture pattern is presented as n-tier architecture and the visual overview is shown in Fig. 1.

In consonance with the requirements of six-sigma and CSE for refined design such that product can withstand stress during usage without failing (Head, 1994), the e-Environment architecture is a clustered architecture with clustered application servers and clustered database servers. In this instance, they are three layers, hence  $n = 3$  and we have a 3-tier architecture as explained in the Table 4.

*C. Certification*

To verify and validate the e-Environment architecture, a prototype was developed using Community Site component of Microsoft SharePoint. The web-based solution was then tested using real-life interactive sessions between stakeholders. As the name implies, the Community Site component facilitated online real-time conversations among environment stakeholders. Test scenarios were presented where service users (requesters) sought for information from the service providers housed in the service registry. To underscore the dynamic collaboration philosophy of the e-Environment system which en-

Table 4. e-Environment architecture explained

SN	Tier	Explanation
1.	Presentation tier	The user interface is the top-most layer of the application. Its primary function is to convert results and tasks into meaningful facts that are comprehensible by environment stakeholders.
2.	Logic tier	This tier is responsible for processing commands, articulating application, evaluating and taking logical decisions, and performing calculations. Additionally, data between the other two surrounding layers are moved and processed by the logic layer.
3.	Data tier	At this layer, the environment database or file system is used to store and retrieve information. The fetched information is transferred to the logic layer for processing prior to returning same to the user.

courages real-time exchange between information users and providers, the prototype ensured that information was provided on real-time basis. This confirmed that e-Environment is a not only web-based, but also service-oriented. Put in another fashion, service users were able to access service providers warehoused in the service registry of the e-Environment system (Okewu, 2015).

#### IV. Results and discussion

Concerned about the impact an innovative system such as e-Environment could make on environmental management initiatives within the broader context of entrenching fiscal discipline in public expenditure, we conducted a test run and assessed the outcomes. The researchers evaluated possible threats to results obtained.

##### A. Results of software experiment

The e-Environment system was built as a community site on Microsoft SharePoint enterprise development platform using cleanroom software engineering techniques. True to its name, the web-based multi-tier enterprise application allows members of the environmental management community – comprising citizens and government officials – to deliberate on topical environment protection and development issues. Underling this software engineering is the environmental message that in the absence of participatory social accountability and transparency in the application of environmental funds, corruption will thrive and the already dilapidated environment would be worse for it (Okewu and Okewu, 2015). We set up an experimental design in University of Lagos, Nigeria precisely at the Centre for Information Technology and Systems and test-run the system from near (Lagos environs) and remote location (from Nigeria's capital, Abuja. Online postings and responses were made from both Lagos and Abuja in real-time.

Going by the reliability standards of cleanroom software engineering approach for design and development, real-life operational data on environmental issues in Nigeria were used (Kaur, 2011; Selby et al., 1987). The experiment confirmed that ICTs could bridge the gap between stakeholders in the environment sector and more importantly entrench transparency and accountability in environmental protection and development. The participants in the experiment agreed that the outcome of the experimental study was seamless and robust online real-time communication among environment stakeholders on topical public policies, programmes, projects and services that are result-oriented. Ultimately, the e-Environment dialogue ignited a sense of transparency procedure capable of promoting participatory environmental accountability for sustainable environment, and by extension national security. Though we experienced platform-dependent and hardware-depend-

ent challenges at the initial stage testing from remote location (Abuja), this suggests that more robust infrastructure is needed for wide-scale implementation in the future.

##### 4.2 Evaluation threats

It is possible that a broader evaluation of the different components of the e-Environment system could throw up new perspective of things. Nonetheless, those who participated in the test run have the required experiential knowledge of the challenges confronting environmental governance in Nigerian – corruption, weak ecological infrastructure, oil spillage in Niger Delta, coastal erosion in South-West region, gully erosion in South East, desert encroachment in Northern Nigeria, among others. They also had adequate hands-on experience with the e-Environment system. This provided them ample platform to make objective assessment of the impact of proposed solution on environmental justice by ensuring judicious utilization of public funds meant for ecological renewal, improved livelihood and national security. Thus, their views can be taken seriously (Host et al., 2000; Runeson, 2003; Sauro, Kindlund, 2005; Svahnberg et al., 25).

Also of note is the small number of participants engaged in the evaluation which potentially could constrain the statistical relevance of the result (Nielsen, Landauer, 1993; Turner et al., 2006). Nevertheless, the outcome of the experiment shows that every aspect of possible stakeholder interactions within the ecological space was adequately covered and robust online real-time conversation ensued. In our view, this is a good result in that at this juncture, the aim is to have a sense of how the e-Environment system could inject transparency and accountability into environmental governance. Hence, regardless of the constraint of few evaluators used, there is adequate grounds to conclude there is a favourable disposition to the e-Environment software system as a tool for enhancing participatory environmental accountability for sustained economic livelihood and national security. It means optimal utilization of state resources such as ecological funds as a consequence of transparency will translate into wellbeing of the citizenry, mitigating social tension and insecurity. We can thus generalize that the CSE-developed e-Environment system is effective for enhancing environmental sustainability, economic stability and national security.

#### V. Conclusion

So far, we have addressed the problem of environmental injustice perpetuated by financial impropriety in the environment sector. Though a number of measures have been advanced before now to stem the tide of corruption militating against environmental protection and development efforts, we unveiled an innovative system approach. The ICT solution, e-

Environment system, empowers environment stakeholders to put forward proposals as well as monitor how budgets on environmental management are spent. This way, excesses of government officials reputed for diverting ecological funds are checked. With state resources judiciously utilized, environmental degradation is checked, socio-economic livelihood improved and national security guaranteed. Apart from solving a problem using cleanroom software engineering approach, the study presents a case study and an industrial experience from the African context as addition the cleanroom software engineering body of knowledge. Finally, the e-Environment system is practical and ecologically sound.

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